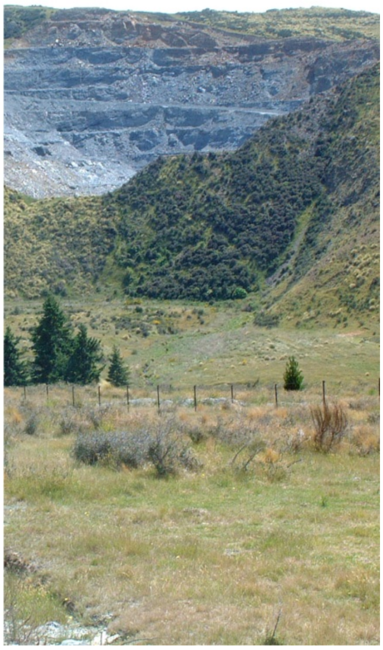
April 2011

## MACRAES PHASE III PROJECT

# Water Quality Effects Mitigation Options

Submitted to:
Oceana Gold (New Zealand) Limited



REPORT

**Report Number.** 0978110-562 R009 vE

**Distribution:**

John Bywater, Oceana Gold (New Zealand) Limited (1 copy)
Maree Baker, Anderson Lloyd Lawyers (1 copy)



Golder Associates

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# Executive Summary

Oceana Gold (New Zealand) Limited is planning to expand their currently consented gold mining operations at Macraes Flat in eastern Otago, approximately 25 km west of Palmerston (Figure 1). The Macraes Gold Project (MGP) consists of a series of opencast pits and an underground mine supported by ore processing facilities, waste storage areas and water management systems. The Macraes Phase III Project includes construction of a new tailings storage facility (TSF), construction of additional waste rock stacks (WRS's), relocation of a current TSF and expansion of several existing opencast pits. OceanaGold is seeking to obtain resource consents authorising the planned Macraes Phase III expansion project.

An integrated water management model has been used to generate water quality projections at current and proposed surface water compliance points associated with the MGP. The model produces projections of contaminant concentrations covering the operational period of the mine and a 150 year post-closure period. Compliance criteria developed for existing Resource Consents, or proposed compliance criteria, have been compared with projected surface water concentrations for each major catchment intersecting the MGP. Water management measures are expected to be required to ensure compliance with the existing and proposed criteria is achieved.

The primary issues for water quality compliance are sulphate, arsenic and iron. Sulphate is less likely to become naturally attenuated in the surface water system than other contaminants. Mitigation is therefore focused around ensuring compliance with the sulphate criteria.

The effectiveness of a variety of water quality mitigation options has been assessed at a screening and initial simulation level, taking into account the practicality of implementation of these options and input from various project stakeholders. The results indicate an appropriate mitigation approach is to combine a suite of measures to address projected water quality issues in the receiving water bodies around the MGP.

The proposed mitigation strategy involves the use of standard adaptive management approaches. The strategy is based on meeting the receiving environment criteria for water quality and demonstrating how compliance could be achieved using the proposed suite of measures but not fixing proposed management and mitigation options. This approach sets the receiving environment criteria and assesses compliance projected to be achieved by a range of options but also assesses options against economic and technical feasibility considerations. Following the assessment of options a range of measures considered appropriate has been adopted for implementation. These measures are subject to adaptive management changes following ongoing monitoring, investigation and bench scale studies and testing of treatment technologies.

The mitigation strategy which has been developed can be summarised in accordance with the following four points:

**Mitigation measures during operational period:** OceanaGold is to continue to implement mitigation measures which are required under current Resource Consents throughout the operational period of the Macraes Phase III Project. Implementation of the water quality management options listed below should enable OceanaGold to continue to meet the receiving environment criteria for water quality for the operational phase of mining:

- Pumping all captured discharges from TSF and WRS areas to the mine water management system, as required by current consents. The effectiveness of this measure at Deepdell Creek and the Shag River has been demonstrated in practice through results from the site environmental monitoring program, where non-compliance events have been minimal.
- Construction of drains to intercept shallow groundwater down-gradient from the Frasers West WRS in the NBWR catchment and pumping the collected water back to the mine water management system.
- Construction of a drain to intercept shallow groundwater around the southern side of the proposed Frasers South WRS and pumping the collected water back to the mine water management system.

**Mitigation measures during post closure period:** A suite of measures has been identified that is considered appropriate to effectively mitigate potential water quality issues associated with the Macraes Phase III Project and also the wider MGP following closure of the site. These measures include:

- Pumping of TSF discharges to Frasers Pit for up to 20 years following closure of each facility to allow discharge flow rates to decrease to the point where other passive mitigation measures (specified below) could be instigated. Once effective passive mitigation measures have been instigated, pumping of TSF discharges to Frasers Pit would cease.
- Installation of an aerobic passive treatment system in or close to Maori Tommy Gully to remove up to 90% of the arsenic and iron from the Mixed Tailings Impoundment (MTI) drain discharges once the flow rates have decreased to the extent that these discharges can be released. Removal of Maori Tommy Gully silt dam.
- Construction of a fresh water dam on Camp Creek to provide a base flow to Deepdell Creek to manage and effectively mitigate sulphate concentrations in Deepdell Creek and in the Shag River as far as the confluence with McCormicks Creek. If necessary, seasonal or flow matched discharges of water may be provided from the proposed Camp Creek dam to effectively mitigate the sulphate concentrations in the Shag River. The actual discharge regime needed to effectively mitigate for the MGP discharges should be determined on an adaptive management basis once monitoring improves our understanding of what concentrations of contaminants and discharge flows from the TSF's eventually need to be managed.
- Passive injection of drainage water and captured groundwater seepage from the TTTSF to the Frasers underground mine. This measure would enable compliance with water quality criteria in Tipperary Creek and assist in compliance with the criteria applicable on the Shag River at McCormicks on a long term basis.
- Continued operation of interception drains for shallow groundwater down-gradient from the Frasers West WRS in the NBWR catchment with discharges to Frasers Pit.
- Continued operation of an interception drain around the southern side of the proposed Frasers South WRS with discharge to the existing backfill in the Golden Ridge Pit (Southern appendix of Frasers Pit), and
- If management or mitigation of iron, arsenic and $cyanide_{WAD}$ concentrations in the Frasers Pit lake is required, this could be achieved through the construction of aerobic passive treatment systems to remove arsenic, iron and $cyanide_{WAD}$ from water pumped to this lake or injected into the underground workings. The same measure could potentially be applied to manage seepage discharges to the Round Hill pit lake. Although this measure is not necessary to enable compliance with water quality criteria downstream from the MGP, it would lead to improvement in the water quality in the pit lake over the short to medium terms.

**Comprehensive monitoring program:** A level of uncertainty is associated with the model projections. To confirm projections for long term compliance with water quality criteria following mine closure, further monitoring and investigation of water quality trends, absorption processes, process water management options and the performance of proposed mitigation measures is required. A water management plan for Macraes Phase III would involve ongoing monitoring at critical monitoring and compliance points, which will be used to confirm projected trends in water chemistry including the assumed model conservatism.

**Recommended compliance limits:** Compliance limits have been proposed for the Macraes Phase III Project which are consistent with current consents for the wider MGP. The water management plan for the Macraes Phase III Project will include an adaptive management approach. Further options, additional or alternative to those considered appropriate at this stage, exist and are expected to be evaluated prior to mine closure as part of this adaptive management approach. The proposed approach to water quality effects management provides options which are considered likely to be effective and therefore provide confidence to project stakeholders. During design of the water management plan further consideration and refinement of the measures proposed is expected to be undertaken.

# ABBREVIATIONS

| | |
|---|---|
| BCR | Biochemical Reactor |
| BOD | Biological Oxygen Demand |
| MIW | Mine Influenced Water |
| MGP | Macraes Gold Project |
| mRL | Relative level, in this case metres above mean sea level |
| MTG | Maori Tommy Gully |
| MTI | Mixed Tailings Impoundment |
| NBWR | North Branch Waikouaiti River |
| RHP | Round Hill Pit |
| SPI | Southern Pit Tailings Impoundment |
| TSF | Tailings storage facility |
| TTTSF | Top Tipperary Tailings Storage Facility |
| WRS | Waste rock stack |

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# 1.0 INTRODUCTION

## 1.1 Background

Oceana Gold (New Zealand) Limited (OceanaGold) is planning to expand their currently consented gold mining operations at Macraes Flat in eastern Otago, approximately 25 km west of Palmerston (Figure 1). The Macraes Gold Project (MGP) consists of a series of opencast pits and an underground mine supported by ore processing facilities, waste storage areas and water management systems. OceanaGold is seeking to obtain resource consents authorising the planned Macraes Phase III expansion project. Golder Associates (NZ) Limited (Golder) has been retained to undertake technical assessments for use in assessing potential for adverse environmental effects which could be associated with the water management aspects of the expansion project.

The Macraes Phase III Project includes construction of a new tailings storage facility (TSF), construction of additional waste rock stacks (WRS's), relocation of a current TSF and expansion of several existing opencast pits. As part of this project Golder has completed assessment of tailings water seepage and contaminant losses from the MGP (Golder 2011a; 2011b) and site wide hydrological modelling to ascertain what effects the continued operation of the mine could have on water quality in the wider catchment (Golder 2011c). These assessments have identified where mitigation of effects is likely to be necessary.

This report presents an assessment options available to mitigate the adverse effects imposed on the surrounding catchment by the Macraes Phase III expansion.[1]

## 1.2 Scope and Report Contents

The purpose of this report is to set out options available to manage and mitigate potential adverse environmental water quality effects that may arise from the proposed Macraes Phase III Project. The potential effects are documented in a separate report (Golder 2011c).

This report presents:

- A summary of projected effects of contaminant losses from the MGP on water quality in surrounding surface water bodies, where these effects may require mitigation.
- A summary and evaluation of mitigation options that may be applied during the MGP operational period, including those that may be integrated into the Macraes Phase III site design - taking into consideration practical issues with instigating the measure, the projected benefits and in some cases a discussion of the inherent risks.
- A summary and evaluation of mitigation options that may be applied following closure of mining operations at the MGP, with similar screening criteria to those applied for options available during the operation period.
- An evaluation of a limited set of potential mitigation measures to assess their efficiency at achieving compliance with existing and proposed water quality conditions outlined in the site wide surface water modelling report (Golder 2011c).
- A summary of mitigation measures considered appropriate to address water quality issues identified for the Macraes Phase III project.

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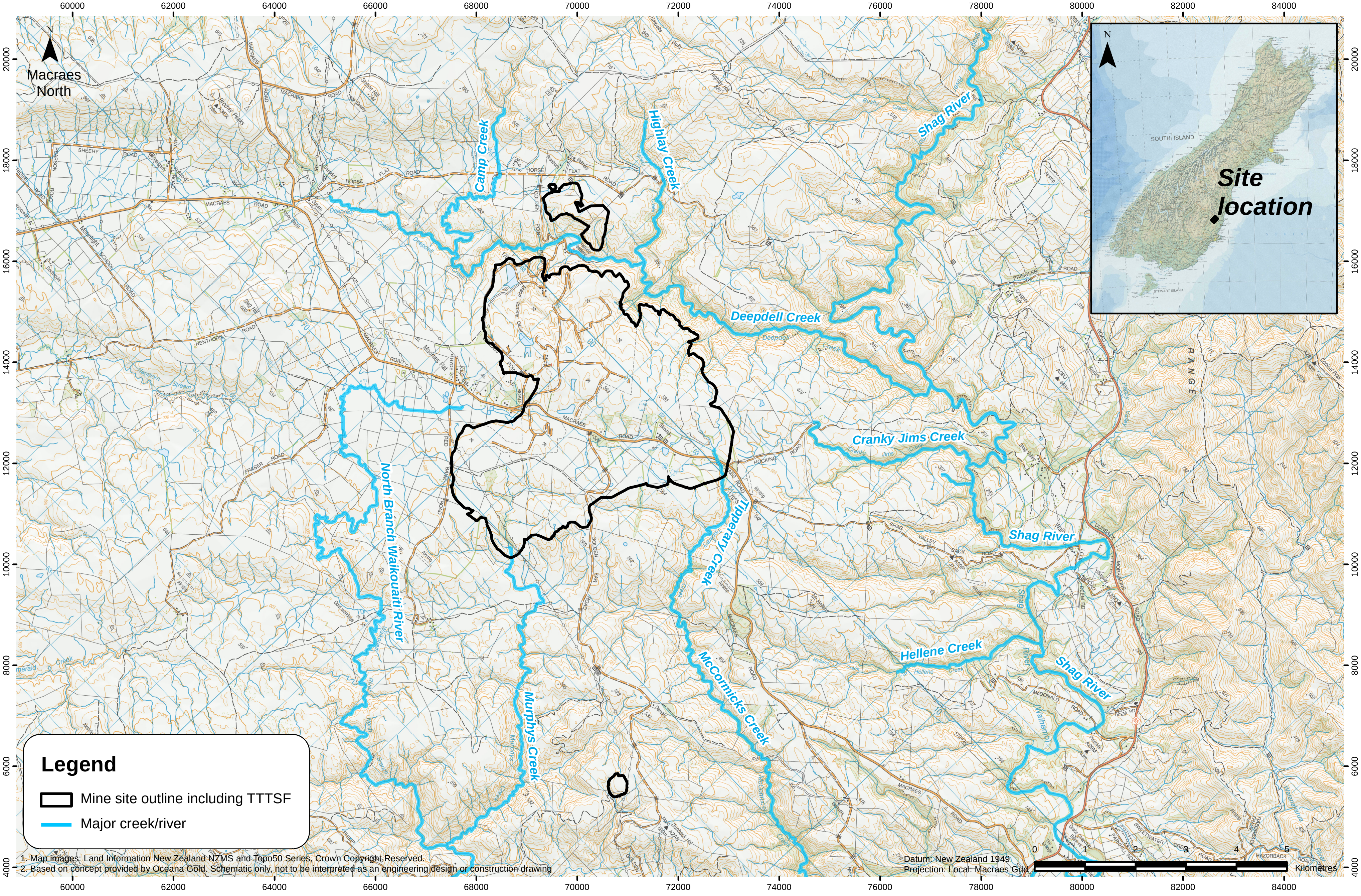
[1] This report is provided subject to the conditions and limitations presented in Appendix A.

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TITLE SITE LOCATION PLAN

**MARCH 2011**

PROJECT 0978110562

**1**

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# 2.0 PROJECTED WATER QUALITY EFFECTS

## 2.1 Introduction

An integrated water management model (Golder 2011c) has been used to generate water quality projections at current and proposed surface water compliance points associated with the MGP. The model produces projections of contaminant concentrations covering the operational period of the mine and a 150 year post-closure period. Compliance criteria developed for existing Resource Consents, or proposed compliance criteria, were compared with projected surface water concentrations at current or proposed compliance points on each major catchment intersecting the MGP (Figure 2).

The outcomes of the water management model with respect to compliance criteria at existing and proposed compliance points are summarised in the corresponding report Golder (2011c). The potential requirement for mitigation measures focused on water quality management upstream from each of these compliance points is also summarised in Golder (2011c). A brief summary of these outcomes is provided in this report.

One baseline mitigation measure was incorporated in the mine water management model, based on post-closure water management measures proposed in 2005 (Kingett Mitchell 2005). It has been assumed that the TSF drainage water from the first 20 years following the close of mining operations at the MGP is actively pumped to Frasers Pit. The projected flows from the TSF drainage systems during this period are considered to be too large and characterised by water quality too poor to efficiently treat prior to release.

The 20 year time period for pumping of tailings drainage water to Frasers Pit is considered to be a conservative estimate. The observed discharge rates from TSF drainage systems decline more rapidly than the model outcomes indicate (Golder 2011d).

It is also likely that some aspects of the discharge water quality would improve over time. The rate of improvement is however very difficult to quantify with any certainty. Consequently, the water management model has incorporated the assumption that seepage and run-off water quality from specific areas of the site improves to a limited extent as operations in these areas cease and rehabilitation is undertaken. No further improvement in mine site water quality over time was incorporated in the model. Contaminant concentrations applied as input parameters to this model are generally at the upper end of the potential range hence outputs are conservative (Golder 2011a).

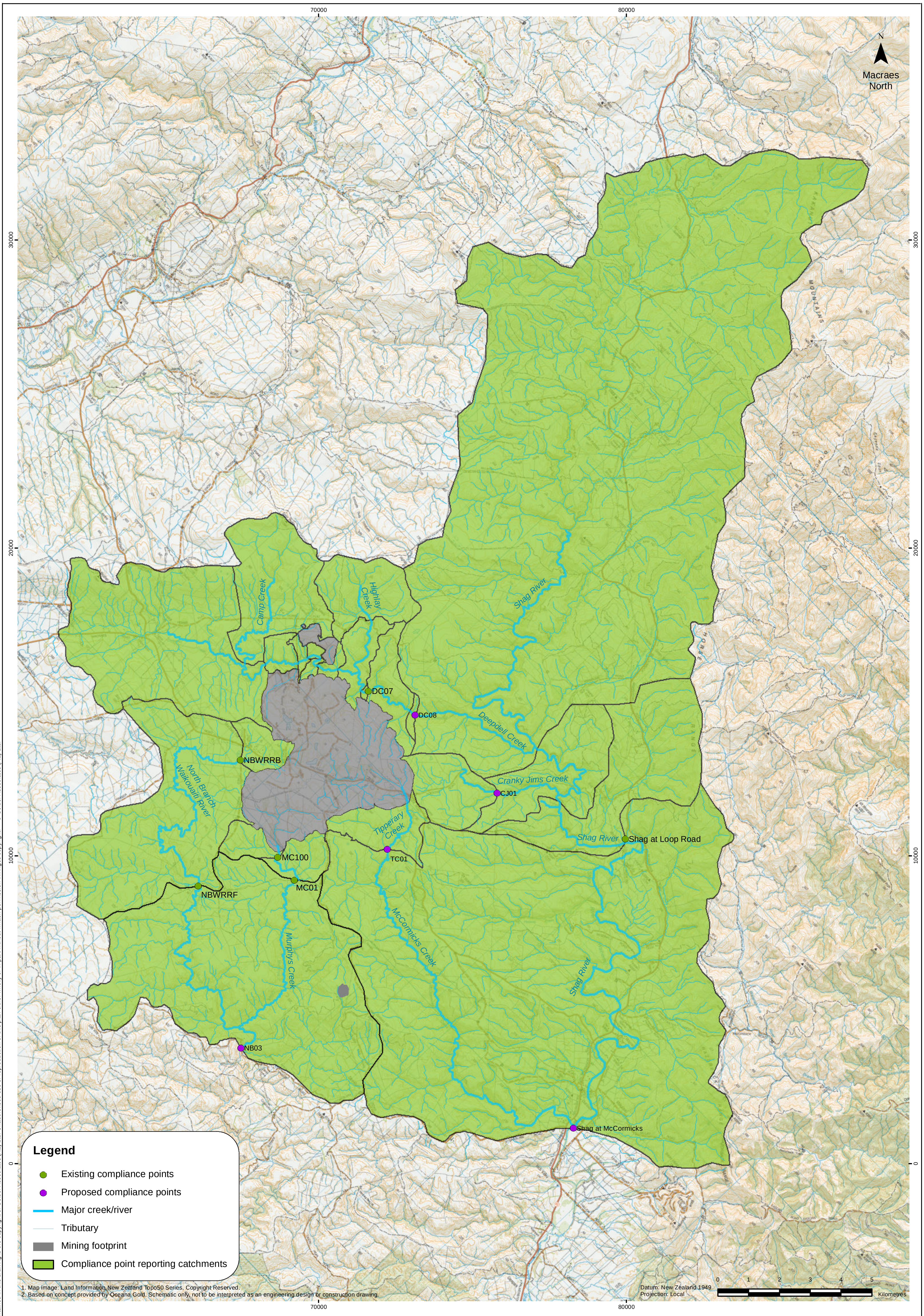
## 2.2 Deepdell Creek

Deepdell Creek receives or will eventually receive groundwater seepage and TSF drainage system discharges from the MGP. Sources of contaminants including the Mixed Tailings Impoundment (MTI), Southern Pit Tailings Impoundment (SPI) and WRS's. Compliance monitoring in Deepdell Creek is proposed to be undertaken at DC08 (Figure 2), as discussed in Golder (2011c).

The primary usage of Deepdell Creek is stock watering. No potable water supply takes are known to exist from Deepdell Creek downstream from the MGP. Access to the creek downstream from the MGP is restricted by the steepness of the valley slopes. The Deepdell Creek discharges into the Shag River, which is used as a source for domestic water supplies.

Contaminant transport routes from the MGP to Deepdell Creek consist of:

- Point discharges from the MTI drainage systems, which are eventually to be discharged to Deepdell Creek.
- Diffuse but localised seepage losses from the MTI and WRS's to tributaries of Deepdell Creek.
- Diffuse seepage losses from the MTI / SPI and WRS's directly to Deepdell Creek.
- Possible losses of water from Golden Point Pit lake to Deepdell Creek (Golder 2011e).



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TITLE
# LOCATION OF SURFACE WATER COMPLIANCE SITES

MARCH 2011

PROJECT 0978110562

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Outcomes from the surface water model (Golder 2011c) indicate mitigation measures would be required to enable OceanaGold to meet the proposed consent water quality criteria at DC08. The primary issue for water quality compliance is expected to be sulphate, as this contaminant is less likely to become attenuated in the surface water system than other contaminants with compliance limits at DC08. Nonetheless, the modelled outcomes are considered to be conservative for this parameter. For example, simulated contaminant mass loads in groundwater discharging to the surface water system are expected to exceed what would occur in reality (Golder 2011b).

Natural attenuation of soluble arsenic is likely to primarily occur through oxidation in conjunction with iron leading to the formation of iron arsenate precipitates. Adsorption of arsenic onto stream substrate is also an important factor in attenuating soluble arsenic in surface water systems. These natural attenuation processes reduce the potential for soluble arsenic concentrations to exceed water quality criteria at DC08.

The precipitation of arsenic and iron can be managed through the construction of aeration systems and wetlands for passive treatment of drain discharges from the MTI. Such wetlands are an appropriate means of arsenic mitigation and have been incorporated in the existing MGP water management plan for water quality mitigation following closure of the MTI. The use of wetlands combined with aeration systems is also appropriate for mitigation of the additional arsenic and iron loading projected as a consequence of the Macraes Phase III Project.

## 2.3 Tipperary Creek

Tipperary Creek is to eventually receive drainage and seepage water from the Top Tipperary TSF (TTTSF) and Frasers East WRS (Golder 2011a). A water quality compliance point is proposed to be established on Tipperary Creek at TC01 (Figure 2). Tipperary Creek discharges into the Shag River by way of McCormicks Creek. Surface water in Tipperary Creek and McCormicks Creek downstream from TC01 is primarily used for stock watering. Water from the Shag River downstream from the confluence is used for domestic water supply.

Results from the surface water model for the MGP indicate the water quality at TC01 would eventually exceed proposed compliance criteria, primarily for arsenic and sulphate. As discussed in Section 2.2, natural attenuation processes are likely to reduce soluble arsenic concentrations to below the proposed water quality criteria at the compliance point TC01 and in the Shag River. Mitigation measures are therefore expected to be primarily required to meet the proposed consent criteria for sulphate at TC01 and at McCormicks. It is expected that the concentrations of soluble arsenic and other contaminants at TC01 would probably also be further reduced by measures instigated for sulphate mitigation.

## 2.4 Cranky Jims Creek

Cranky Jims Creek is expected to eventually receive seepage water from the TTTSF (Golder 2011a), both from the tailings and from the waste rock used to construct the embankment. A water quality compliance point is proposed to be established on Cranky Jims Creek at CJ01 (Figure 2). Usage of surface water from Cranky Jims Creek is primarily for stock watering. Cranky Jims Creek discharges into the Shag River, which is used as a water source for domestic supply.

It is expected that compliance for the proposed criteria at CJ01 is likely to be achieved during operation of the project and following closure (Golder 2011c). No measures are considered necessary to mitigate for seepage losses from the TTTSF to Cranky Jims Creek. The reduction of contaminant loads discharging to Cranky Jims Creek may, however, reduce the risk of non-compliance at the Shag River water quality compliance points.

## 2.5 Shag River

Water from Deepdell Creek, Cranky Jims Creek and Tipperary Creek (by way of McCormicks Creek) discharges into the Shag River. The Deepdell Creek confluence is the most upstream of the three. The existing MGP water quality monitoring location for the Shag River is located at the upstream Loop Road crossing, downstream from the Deepdell Creek confluence, but upstream of the McCormicks Creek confluence. An additional water quality compliance point is therefore proposed for a location a short distance downstream from the McCormicks Creek confluence.

There are several existing water takes from the Shag River for potable water. For that reason the water quality compliance limits at Loop Road relate to the New Zealand drinking water standards. The proposed water quality limits downstream from the McCormicks Creek confluence are the same as those applied at Loop Road.

The water management model results indicate the water quality at both Loop Road and the compliance point downstream from the confluence with McCormicks Creek may eventually exceed the compliance limit applicable for sulphate. As discussed in Section 2.2, natural attenuation processes are likely to reduce concentrations of soluble arsenic to below the compliance criteria at both water quality compliance points in the Shag River.

Mitigation measures are likely to be required to meet the proposed criteria for sulphate at the Shag River monitoring sites. Concentrations of other contaminants detected in mine influenced water (MIW), such as arsenic and iron, would be further reduced through the same measures employed to mitigate for sulphate.

## 2.6 Murphys Creek

Murphys Creek receives seepage and run-off water from the Frasers West WRS. The proposed compliance monitoring location for Murphys Creek is site MC01, located approximately 1 km downstream from the Murphys Creek silt pond. Murphys Creek discharges into the North Branch Waikouaiti River (NBWR). Consent compliance monitoring in the NBWR is currently undertaken at NB03 (Figure 2), which is downstream of the confluence of Murphy’s Creek and the NBWR.

Water from Murphys Creek is primarily used for stock watering. Downstream of NB03, water from the NBWR is abstracted to maintain levels in the Stoneburn Reservoir. This reservoir forms part of the Stoneburn Rural Water Supply Scheme operated by the Waitaki District Council. The Stoneburn water abstraction is for domestic and stock water supply purposes.

As discussed in Section 2.2, natural attenuation processes are likely to reduce soluble arsenic concentrations to below the proposed compliance criteria at MC01. Sulphate is not currently a water quality compliance parameter at this location, however a compliance limit of 1,000 $g/m^3$ is proposed (Golder 2011c). The water management model projections indicate that sulphate concentrations at MC01 are likely to remain less than 1,000 $g/m^3$, both during operations and post-closure. Monitoring of water quality trends in Murphys Creek however suggest this sulphate concentration is likely to be exceeded during the operational period of the mine.

These observed water quality trends at MC01 differ from model projections. The model however does not take into account OceanaGold’s occasional historical practice of irrigating water from Frasers Pit onto the Frasers West WRS, leading to increased seepage flows through the WRS and increased contaminant mass loads. This irrigation has been periodically undertaken to limit the accumulation of water in the Frasers Pit sump during substantial rainfall events. Irrigation is to be discontinued in favour of direct discharges to the NBWR and Murphys Creek, following which the measured downstream concentrations are expected to more closely correspond to the simulation outcomes. Monitoring water quality trends at MC01 would also be useful for assessing whether future exceedances at NB03 may be a concern.

Based on the observed water quality in Murphys Creek upstream from MC01, it is likely that mitigation will be required in order to meet the proposed compliance limit for sulphate during the operational period of the mine. Golder recommends the current upstream compliance point at MC100 should no longer be used as a water quality compliance point due to the need to provide space for the provision of mitigation measures (Golder 2011c). OceanaGold own the land in this area and can manage stock access to the water.

## 2.7 North Branch Waikouaiti River

The NBWR receives seepage water and surface run-off from the Frasers West WRS. The proposed compliance monitoring points for water quality in the NBWR are at the Red Bank Road crossing (NBWRRB) and at NB03. Usage of water upstream of NB03 is considered primarily to be for stock watering purposes. Downstream of NB03, water from the NBWR is abstracted to maintain levels in the Stoneburn Reservoir, as described above.

Natural attenuation processes discussed in Section 2.2 are likely to reduce concentrations of soluble arsenic to below the compliance criteria at NBWRRB and NB03. Mitigation for arsenic is therefore not considered to be necessary to ensure compliance with water quality limits.

Sulphate does not currently have a compliance limit at NBWRRB. Model results and observed water quality trends indicate the proposed limit of 1,000 $g/m^3$ may seasonally be exceeded both during the operational period and post-closure. Mitigation measures applied to manage sulphate concentrations in the NBWR are very likely to also result in further reduction of the projected soluble arsenic concentrations at NBWRRB.

Sulphate is not currently subject to a compliance limit at NB03. The proposed compliance limit is 250 $g/m^3$. Mitigation measures to ensure compliance with this limit may become necessary both during the MGP operational period and following site closure. Ongoing monitoring of the upstream compliance sites on the NBWR and Murphys Creek should provide good indications on the necessity for sulphate mitigation measures.

## 2.8 Limitations of Projected Water Quality for Assessing Mitigation Options

The water quality outcomes of modelled mitigation options are reported as the $99^{th}$ percentile concentration rather than the maximum projected concentration as indicated in Golder (2011a). Use of the $99^{th}$ percentile does not imply the water quality is likely to exceed compliance limits 1% of the time. The $99^{th}$ percentile is considered an “effectively mitigated” outcome for the simulations, taking into account model and sampling limitations and is reported using this term for the remainder of this report.

Use of a $99^{th}$ percentile for assessing the likely achievement of compliance is considered appropriate rather than the maximum projected concentrations for the following reasons:

- The surface water model is founded on an extensive data set which includes extreme precipitation (wet and dry) conditions. The model water quality outputs under extreme dry conditions are logically the highest concentrations as the factor of dilution is the lowest. No adjustments in the model are made for reductions in discharges which may occur at other site features as a result of low rainfall or dry conditions (changes to land surface conditions, reduced groundwater gradients, etc.). By comparing compliance limits to the $99^{th}$ percentile of each data set, a conservative approach to evaluating likely maximum concentrations at compliance points is maintained while eliminating the unlikely extreme combinations of conditions that arise in the model.
- Conservative assumptions in the model result in water quality outcomes which are likely over-estimated. Use of the $99^{th}$ percentile helps to balance conservatism with the need for practicality.
- Monitoring compliance against maximums is statistically complex and expensive to ensure sampling frequency is sufficient to identify maximum concentrations within waterways. As even with maximum concentrations there is always a statistical probability that they will be exceeded. Monitoring against $99^{th}$ percentile compliance with consented limits is therefore more practical, statistically achievable and affordable whilst ensuring effects are acceptable.

The use of targets below modelled maximums is common in regulatory frameworks for the above stated reasons. Further discussion of the limitations and model conservatism is provided in Golder (2011c).

## 3.0 IDENTIFICATION OF WATER QUALITY MITIGATION OPTIONS

The focus of new mitigation options reviewed for the Macraes Phase III Project is the management of potential sulphate concentrations in Deepdell Creek and Tipperary Creek, thereby also reducing their potential concentrations in the Shag River. In addition, measures to manage sulphate concentrations in Murphys Creek and the NBWR have been considered in this section, although the Macraes Phase III Project is expected to generate relatively minor effects in these catchments over and above those already projected from existing operations.

There are a range of technologies or methods which can be used to mitigate the potential effects associated with discharge of MIW. These mitigation measures may be applicable during design phase (e.g., installation of a liner system during construction of the TTTSF), during operating stages of mining (e.g., use of water for processing or pumping TSF drain discharges to Frasers Pit), or during post closure stages (i.e., passive treatment of residual MIW from TSF drains after dewatering has occurred). Following discussions with OceanaGold environmental and operational staff, a list of possible mitigation options have been identified as potentially applicable. The mitigation measures considered in this report are summarised in Table 1.

**Table 1: Summary of mitigation options under consideration.**

| Mitigation type | Mitigation option | Applicability |
|---|---|---|
| Intercept and re-route MIW to location other than directly to surface water catchments. | Construction of underdrains at new TSF's and new WRS's. | TTTSF, Back Road WRS and Frasers South WRS's. |
| | Pumping collected TSF drain discharges and groundwater seepage to Frasers Pit – baseline mitigation. | MTI, SPI and TTTSF discharges following TSF closure. |
| | Divert TSF drain discharge water to Frasers Pit on a permanent basis. | TTTSF. |
| | Pump WRS runoff and shallow groundwater seepage to Frasers Pit or Golden Point Pit. | Frasers WRS's and Back Road WRS. |
| | Divert WRS run-off and shallow groundwater seepage to Frasers Pit or Golden Point Pit. | Frasers South and East WRS's and Back Road WRS. |
| Dilute groundwater contaminant plumes prior to discharge. | Enhanced recharge of WRS runoff to groundwater (managed groundwater recharge). | Frasers West WRS and Back Road WRS. |
| Creek base flow augmentation through construction of freshwater dams to allow for dilution to surface water bodies which receive direct discharge of MIW. | Camp Creek, Highlay Creek or Deepdell Creek freshwater dam, without augmentation. | Deepdell Creek and Shag River during operations or post-closure. |
| | Camp Creek, Highlay Creek or Deepdell Creek freshwater dam with augmentation from Taieri or other source. | |
| | Managed release from Lone Pine Reservoir to Deepdell Creek. | |
| | Tipperary Creek freshwater dam, upstream location, possibly with augmentation from Taieri or other source. | Tipperary Creek and Shag River during operation or closure stages |
| | Tipperary Creek freshwater dam, downstream location. | |

| Mitigation type | Mitigation option | Applicability |
|---|---|---|
| | Groundwater bores to supplement flows in Tipperary Creek. | Tipperary Creek during operational stages |
| Hydraulic control of MIW and reduction of potential for leaching through construction of low permeability caps and liners. | Low permeability cap on MTI, SPI, TTTSF or WRSs. | All surface receiving water bodies post-closure. |
| | Removal of Maori Tommy Gully silt pond. | Deepdell Creek and Shag at closure. |
| | Partial low permeability liner on base of TTTSF. | Tipperary Creek and Shag River during operations and post-closure. |
| | Full low permeability liner on base of TTTSF. | |
| | Full encapsulation of TTTSF. | |
| MIW treatment prior to discharge. | Active treatment of process water. | Deepdell Creek, Tipperary Creek and Shag River post-closure. |
| | Active treatment of TSF drain discharges and groundwater seepage. | Deepdell Creek, Tipperary Creek and Shag River post-closure. |
| | Passive treatment of TSF drain discharges and groundwater seepage. | Deepdell Creek, Tipperary Creek and Shag River post-closure. |
| | Passive treatment of WRS groundwater seepage | All affected surface receiving water bodies where mitigation indicated. |
| | Covered evaporation basins for WRS runoff and groundwater seepage. | |

The identified options are discussed in the following sections, including a description of the option and its technical, practical and economic feasibility. Detailed descriptions and the evaluation outcomes for several mitigation options are appended to this report. Following the discussion of the individual options, the options considered to have the greatest potential for water quality management at the MGP have been identified (Section 7.3). The report concludes with summary of a water management regime which could be implemented by OceanaGold to meeting water quality objectives for the Macraes Phase III Project (Section 8.0).

# 4.0 DEEPDELL CREEK AND SHAG RIVER EFFECTS MITIGATION

## 4.1 Back Road WRS Underdrains

Groundwater modelling indicates the Back Road WRS would generate a wide diffuse plume discharging contaminants, primarily sulphate, to Deepdell Creek. Reduction of this contaminant load could improve long term water quality at compliance point DC08.

The installation of underdrains in the gullies intersecting the proposed WRS is one potential means of capturing waste rock seepage before it enters the underlying rock mass. The underdrain discharges could be managed over the long term if necessary to meet compliance conditions. Further details of underdrain assessment is provided in Appendix B.

Underdrainage of a WRS is however not necessarily an efficient means of reducing contaminant discharges to Deepdell Creek. It is likely that the seepage water collected by the underdrains would have discharged to silt ponds or traps downstream from the WRS in any case. The water from these silt traps could be captured and managed without the necessity of installing extensive underdrains.

The main benefit underdrains provide over the capture of seepage using silt traps is the stability of flow rates without the issues of variable surface run-off to manage. This benefit could also be achieved through the installation of small groundwater interceptor trenches that could be installed inside the toe of the proposed WRS with a discharge drain to a water management system downstream from the WRS. The relative costs of the three options for WRS groundwater management would need to be evaluated in more detail to identify the most cost effective means of capturing WRS seepage.

Underdrains allow capture of a proportion of WRS seepage however the captured water would still need management. Underdrain installation alone is unlikely to constitute a water quality mitigation measure on its own.

## 4.2 Closure Stage Mitigation Options

### 4.2.1 Creek base flow augmentation

#### *4.2.1.1 Fresh water dam*

The availability of in-stream water to dilute mine water discharges is lowest during low flow periods in Deepdell Creek. Augmentation of the base flow in Deepdell Creek offers an opportunity to increase dilution during periods when the risk of non-compliance with water quality criteria is greater.

A fresh water dam located in the Deepdell Creek catchment could be used to help mitigate non-point source water quality issues by providing greater base flow reliability. Run-off collected during periods of higher rainfall could be stored in the dam and either released as required to supplement base flows in the creek during low flow periods or released as a constant discharge. By decreasing the frequency of critical low flows, the risk of non-compliance with consented water quality limits is greatly reduced as modelling and observation show that there is a strong correlation between low flows and elevated contaminant levels. This is not surprising since groundwater seepage rates remain relatively constant whereas surface flows are more variable and respond much more rapidly to changes in catchment surface water inflows.

Preliminary modelling has been undertaken to assess the minimum baseflow likely to be required to maintain water quality within compliance limits in Deepdell Creek and the Shag River. The modelling has also been used to evaluate the position, size and potential base flows achievable from dams that could be constructed at several possible locations within the Deepdell Creek catchment. Review of the options and consenting issues that may arise has resulted in three dam options being assessed to evaluate their potential to deliver the required minimum baseflow.

Three fresh water dam scenarios have been evaluated as potential mitigation options to ensure the MGP meets water quality compliance concentrations for a range of contaminants in Deepdell Creek and the Shag River at their respective compliance monitoring points. The possible dam locations identified are on Camp Creek (Figure 3), Highlay Creek (Figure 4) and Deepdell Creek upstream from the Maori Tommy Gully confluence (Figure 5). Further modelling was undertaken to investigate the viability of these three dam locations.

These base flow augmentation scenarios are based on the assumption that a dam could be constructed that would either:

- Release water at a constant rate throughout the year and thereby supplement downstream flows during natural low flow periods, or
- Release water on a seasonal or flow matched basis while retaining water during periods when flows are higher.

These supplementary flows would provide additional dilution to discharges from the mine site.

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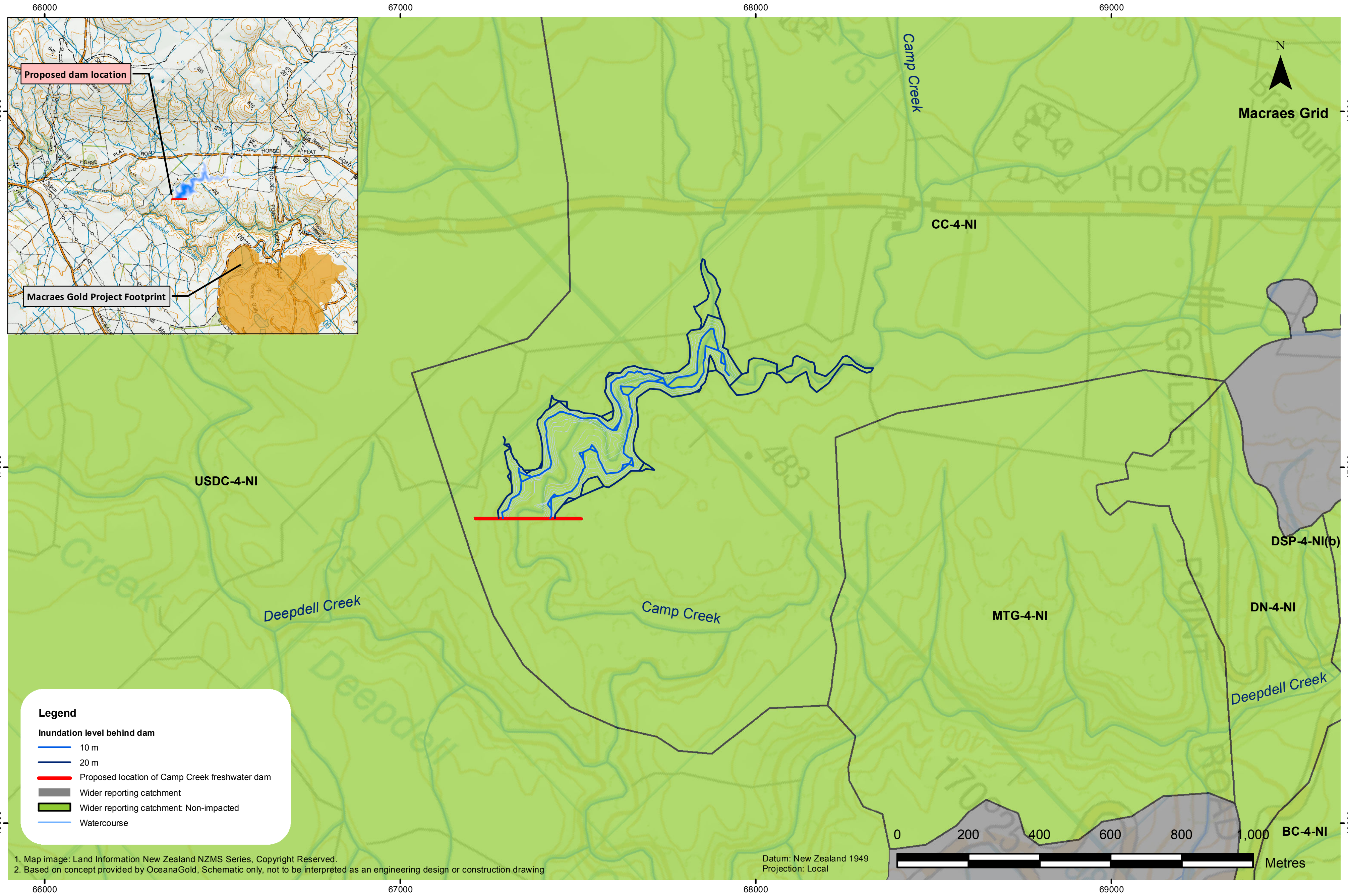




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TITLE

# CAMP CREEK DAM SITE LOCATION PLAN

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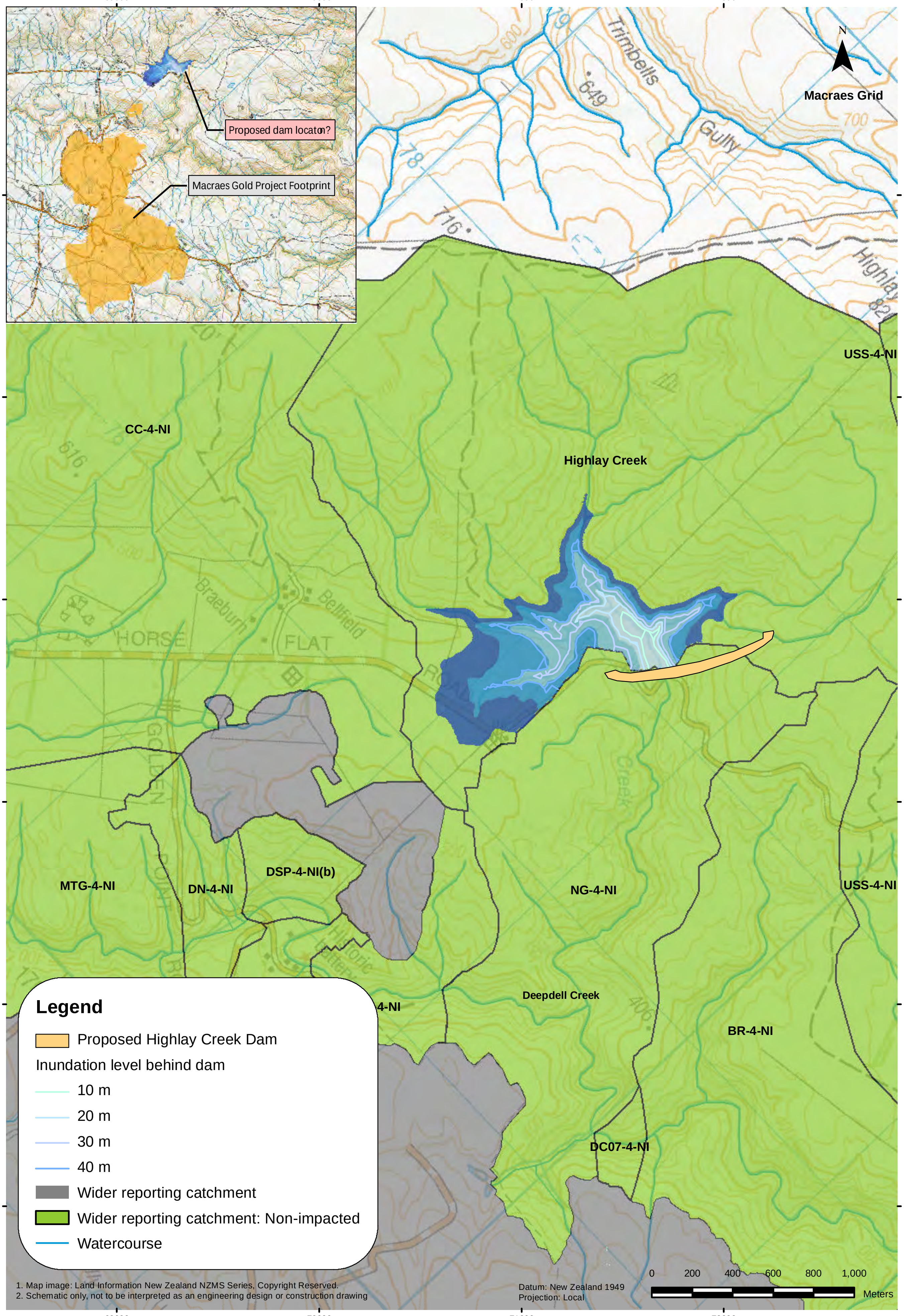


1. Map image: Land Information New Zealand NZMS Series, Copyright Reserved.
2. Schematic only, not to be interpreted as an engineering design or construction drawing



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TITLE HIGHLAY CREEK DAM SITE LOCATION PLAN

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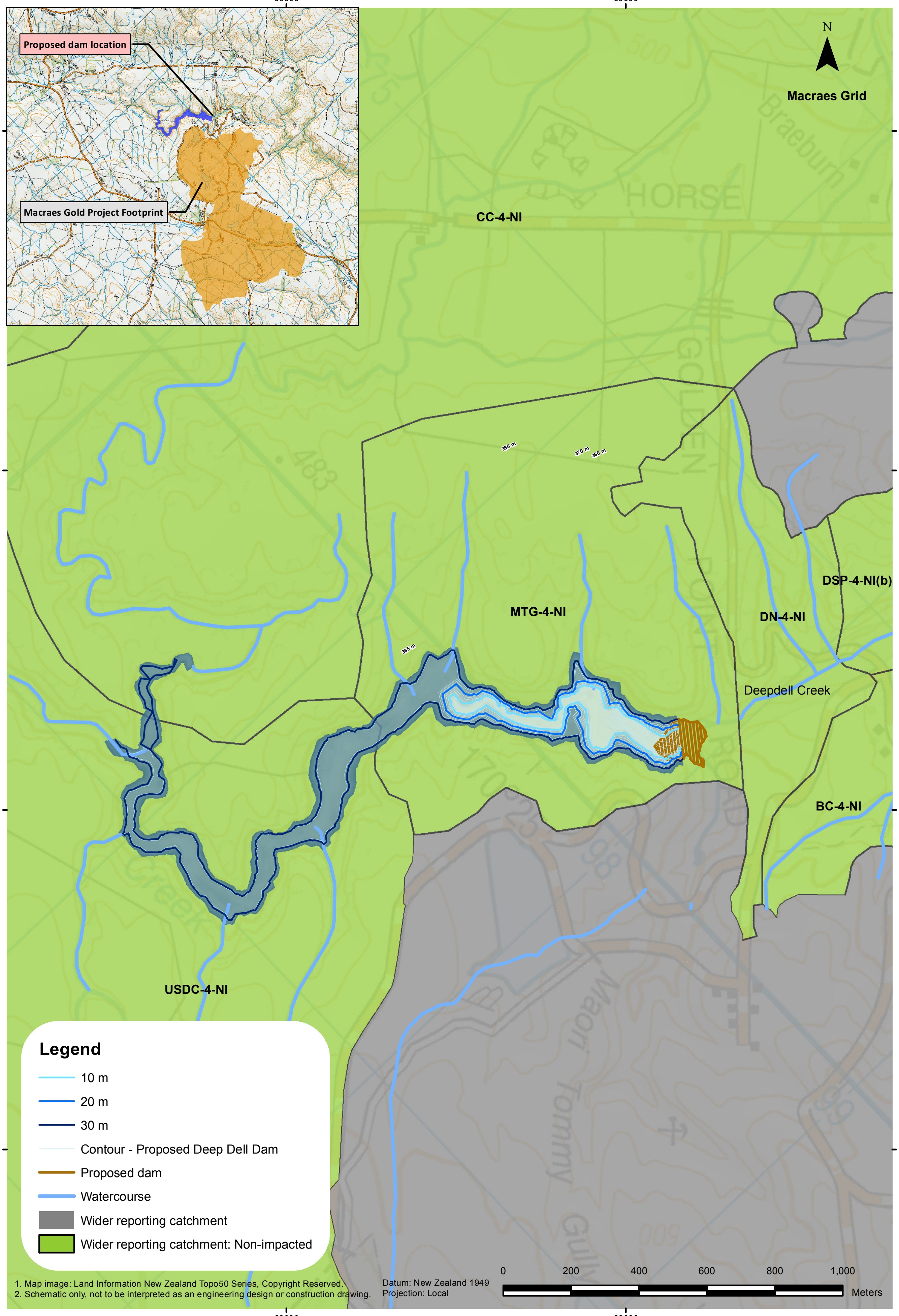




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TITLE **DEEPDELL CREEK DAM SITE LOCATION PLAN**

**MARCH 2011**

PROJECT 0978110562

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Due to the somewhat seasonal nature of the flows in Deepdell Creek and the Shag River, a simulated constant flow discharge from any of these dams does not maximise the opportunity to provide dilution water during the dry summer periods, when the risk of non-compliance is greatest. Managed releases of water from these dams, on a seasonal or flow-matched basis, could reduce the risk of non-compliance without increasing the water storage capacity of the dam

The primary water management issues for the use of fresh water dams for mitigation purposes are:

1) The time required to fill each of the dams.

2) The maximum discharge rate that could be maintained by each of the dams.

3) Maintaining a small residual flow in the creek downstream from the dam for ecological protection purposes.

Modelling indicates construction and operation of a dam on Camp Creek to the maximum proposed size could provide a continuous release of up to 10 L/s to supplement the low flows in Deepdell Creek at DC08. A substantially larger release rate based on a seasonal or staged discharge is achievable from the same dam.

The surface water model incorporating the Camp Creek dam indicated that this scenario effectively mitigated the MGP discharges to the water quality criteria applicable at DC08. The simulation indicated that a water release rate of 10 L/s would however not quite effectively mitigate for sulphate at Loop Road.

The model indicates the Camp Creek dam could achieve a seasonal or flow matched discharge of 16 L/s, which would be sufficient to effectively mitigate for sulphate at the Loop Road compliance point (Appendix B). Higher discharge flows are achievable for shorter durations of release. The simulation did not indicate the MGP discharges could be effectively mitigated with respect to arsenic at the Loop Road compliance point, however the simulation was unrealistic in that respect as it did not take into account natural attenuation or other mitigation measures and this issue is addressed below.

Staging of the discharges from the Camp Creek dam based on continuous monitoring of flow rates in either Deepdell Creek of the Shag River was considered as a means to achieve effective mitigation of sulphate at Loop Road. The actual discharge regime needed to achieve compliance should be determined on an adaptive management basis once monitoring improves our understanding of what concentrations of contaminants and discharge flows from the TSF's eventually need to be managed. The modelling represents a worst case scenario, to demonstrate that water would be available to effectively mitigate for the MGP discharges. However a refined discharge regime should be based on the outcomes from monitoring of mine water discharges following closure of the MTI and eventually of the MGP as a whole.

The mine water management model is considered to be more conservative with respect to water quality projections for the Shag River than for Deepdell Creek. This expectation is supported by observed water quality at DC07 and Loop Road during November 2006. At that time inadvertent releases of mine water resulted in sulphate concentrations in Deepdell Creek exceeding 1,000 $g/m^3$. At about the same time the observed sulphate concentration in the Shag River at Loop Road was less than 160 $g/m^3$. Since that time the observed sulphate concentrations at Loop Road have not exceeded 50 $g/m^3$, whereas the concentrations at DC07 have reached or exceeded 500 $g/m^3$ twice. These ratios indicate that if compliance with the sulphate criterion at DC07 or DC08 can be achieved, then it is likely that compliance would also be achieved for sulphate at Loop Road.

Modelling indicates a dam on Highlay Creek could provide a continuous release of approximately 4 L/s to supplement the low flows in Deepdell Creek. A substantially larger managed release rate is also achievable from the same dam. The surface water model incorporating the Highlay Creek dam however indicated compliance with sulphate limits for Deepdell Creek and the Shag River could not be achieved using this dam as the sole source of dilution water. This is a consequence of the relatively small catchment area and associated small potential constant rate of water discharge. The Highlay Creek dam option was not further developed.

Modelling indicates that the Deepdell Creek dam could sustain a constant release rate of approximately 26 L/s. This baseflow would be sufficient to mitigate arsenic and sulphate concentrations at DC08. Simulation of this scenario indicated the MGP discharges could be effectively mitigated with respect to sulphate in the Shag River at Loop Road. The simulation did not indicate compliance could be achieved for arsenic at the Loop Road compliance point, however the simulation did not take into account natural attenuation or other mitigation measures (and in that respect is unrealistic as discussed above). While a dam on Deepdell Creek would be feasible from an engineering perspective, Golder has been advised by OceanaGold that such a dam would give rise to a number of issues concerning in-stream ecological values. Accordingly this option has not been considered further.

Reservoir filling scenarios for the proposed Camp Creek, Highlay Creek and Deepdell Creek dams were run using modified versions of the mine water management model for the MGP site (Golder 2011c). The projected filling times for the simulated dams were 2 to 8 years for Camp Creek, 3 to 12 years on Highlay Creek and approximately seven months for Deepdell Creek, depending on weather conditions during the years following construction (Appendix B). These filling times are based on the assumption that no residual discharge of water from the dam would be occurring during the filling period.

Concerns regarding the effects of decreased flow during the filling time for the freshwater dams can be mitigated by allowing a minimal residual flow from the dam to address ecological effects. This residual flow rate may increase the time required for the dam to fill. A summary of mine related flow effects is presented in Appendix C.

#### 4.2.1.2 Lone Pine Reservoir

The Lone Pine water storage reservoir (Lone Pine) is located in the Maori Tommy Gully catchment to the northwest of the process plant. Lone Pine currently acts as the water source for the process plant, however it has the potential to act as a long-term storage dam discharging to Deepdell Creek. If used as such, Lone Pine could contribute to the maintenance of a baseflow in Deepdell Creek in order to reduce the risk of non-compliance with consented water quality limits.

The concept is based on a modification of the mine run-off drainage system following closure to ensure that Lone Pine receives the run-off from the MTI. Simulations indicate Lone Pine by itself does not have sufficient catchment area and resulting run-off to prevent critical low flows in Deepdell Creek. Inflows to the reservoir following closure are ephemeral and have median and average flows of less than 1 L/s and approximately 4 L/s, respectively. Modelling indicates that Lone Pine would occasionally be empty if utilised for a dilution water source. For this reason Lone Pine is not considered suitable for a water source. Lone Pine could however play a role in supporting other mitigation measures implemented in the catchment.

### 4.2.2 Passive water treatment systems

Passive treatment of TSF drainage water using wetlands is already one component of the closure plan for the MGP. A similar water treatment process would be effective for managing the extra arsenic and iron contaminant loads arising from the Macraes Phase III Project TSF discharges. The removal of arsenic and iron could be achieved through instigating the following water treatment option on the collected TSF discharges:

- ***Iron-Arsenic Aerobic Cell:*** A passive aeration system followed by an aerobic reed bed populated by wetland plant species. Some of the iron and most of the arsenic contained in the water should be removed by this process.

The installation of the aerobic cell is expected to substantially reduce iron and arsenic concentrations in the discharge water together with other metals that may also become oxidised and combine with the iron or otherwise precipitate. $\text{Cyanide}_{WAD}$ is also expected to break down during passage through this cell. An aerobic wetlands can be constructed at locations on the site conducive to interception of gravity drained MIW prior to discharge to surface water bodies. For example, construction of an aerobic wetland is already planned in Maori Tommy Gully to intercept drainage and seepage flow from the MTI as part of the existing site water management plan. The aerobic cell would reduce the possible development of iron flocculants and staining in Maori Tommy Gully and Deepdell Creek. Additionally, TSF discharges eventually directed to the Frasers Underground mine or Frasers Pit lake could be treated using an aerobic wetland to improve water quality with respect to arsenic and iron.

Passive treatment options also exist for sulphate, although the costs associated with this measure is significantly higher than creation of an aerobic wetland. Additionally, removal of sulphate, primarily through the use of sacrificial iron, can create a requirement for polishing treatment discharges for iron or manganese. A system likely to reduce sulphate concentrations from drain and seepage water may be comprised of the following two cells in addition to the iron-arsenic aerobic cell described above:

- ***Biochemical Reactor (BCR) with Sacrificial Iron:*** A biochemical reactor with a substrate amended with a source of sacrificial iron would be suitable to remove the sulphate via bacterial mechanisms. The effluent from this unit may however contain more dissolved iron than the original influent.
- ***Aerobic Biochemical Oxygen Demand and Iron Polishing Cell:*** A final aerobic reed bed could be used to re-oxygenate the BCR effluent, precipitate the iron gained in the BCR, remove any biochemical oxygen demand (BOD) and precipitate any manganese present.

A combination of all three stages is likely to produce effluent that is virtually free of iron and arsenic, with sulphate concentrations reduced by at least an order of magnitude. Since the individual components of the passive treatment system outlined above are targeted to treat particular contaminant suites, the components can be separated for use in combinations with other mitigation options. For example, treatment for arsenic through an iron-arsenic aerobic cell can be combined with a freshwater dam for mitigation of sulphate and this is the preferred combination identified in Section 7.0 of this report.

Projected water quality outcomes from surface water modelling indicate passive treatment is a viable option for reducing contaminant concentrations in water draining from the TTTSF and the MTI/SPI areas. Models have been used to simulate the scenarios of contaminant reductions in TSF drain discharges and collected groundwater seepage from the TSF's by 75% and 90%, both of which are considered to be achievable. If passive treatment systems were installed to reduce the arsenic and sulphate concentrations in collected TSF discharge water by 90%, the models indicate the MGP discharges could be effectively mitigated to the water quality criteria applicable at DC08 and at Loop Road (Appendix B).

### 4.2.3 Low permeability TSF cap

Current rehabilitation planning for the TSF's incorporates the placement of a soil and waste rock cover on top of the tailings. Although the cap design has not yet been finalised, the objective is to reduce rainwater infiltration to the equivalent of the regional recharge rate. It is considered that this objective is achievable.

It is considered unlikely that a lower recharge rate to stored tailings could be achieved through simply applying a low permeability cap using materials available at the site. This conclusion is partly based on the probable lack of sufficient low permeability capping material at the site.

Constructing an impermeable cap using clay, geotextiles or other forms of artificial covering material could potentially reduce the rate of infiltration. A modified groundwater model was developed for the TTTSF which simulated the infiltration rate through the tailings surface to zero. The result showed seepage losses were reduced. At the end of the 150 year simulation period however the simulated seepage rate was still declining. At that stage the drain flows were approximately 60% of the simulated drain flows from the uncapped TSF.

Although the groundwater model is likely to substantially understate the rate at which the drain flows decrease following closure, it is unlikely that the initial rate of decrease would be accelerated significantly due to an impermeable cap being installed. Over the long term capping of the TSF could negate the need to apply other permanent mitigation measures to the catchment. The time required before the point at which no further mitigation would be required is however uncertain and it is probable some form of mitigation would be needed during the intervening period. It is doubtful that the drain flows, even with capping, would ever decline to zero.

Capping the MTI and SPI in this manner would be an expensive project, and would not be a complete solution. Ongoing issues that would still arise with capping include:

- Ongoing monitoring and maintenance. This option does not provide a permanent solution to the potential contamination of the surrounding catchment unless regular monitoring and maintenance of capping materials is implemented.
- Potential dying off of re-vegetation. The wetting and drying cycle in the soils overlying the cap would be more extreme than in those across the remainder of the site. Major rainfall events could lead to soil saturation while the summers would probably be characterised by extended periods of parched soils. The limited rooting depth would limit vegetation capacity to access moisture in deeper soils.
- Erosion due to run-off can lead to exposure of the impermeable layer, with the attendant risk of damage.
- Limits on use. Potential post-closure land use options of the capped surface are limited by the above issues.

# 5.0 TIPPERARY CREEK AND SHAG RIVER EFFECTS MITIGATION

## 5.1 Design-Phase Mitigation

Prior to construction of the Macraes Phase III waste storage facilities, design elements may be used to reduce potential concentrations of arsenic, sulphate and metals in surface receiving waters. This primarily pertains to construction of the TTTSF and new or expanded WRS's. A short summary of several options reviewed is presented below however none of those listed provided substantial benefits that justified detailed evaluation.

***Hydraulic Controls*****:** Low permeability liners or zones could potentially be used to slow or limit seepage flows through tailings or waste rock. Drains (course materials or pipes) could be used to accelerate discharge or route it to preferred locations for treatment.

***Encapsulation:*** The installation of a low permeability liner in combination with low permeability capping material could be used to encapsulate materials likely to leach arsenic, sulphate or other contaminants. Encapsulation is however not likely to be a practical approach for managing water quality effects at the MGP. Due to the continual discharge of tailings and associated water into a TSF, the tailings cannot be encapsulated until the close of the operational TSF period unless it was done on a cellular basis. Upon closure the stored tailings are effectively fully saturated. Even with drainage systems installed within the encapsulated cell, pore water could take in excess of 100 years to drain to steady state conditions. Encapsulation prior to achieving steady state groundwater levels would imply continual outward gradients within the encapsulation cell, which would likely lead to an eventual breach and release of water, thereby negating the effectiveness of this approach. The relatively high costs associated with liner and cover materials, the requirement to maintain cover materials in perpetuity and the marginal effectiveness of full encapsulation of tailings suggest this option should not be considered for mitigating surface water quality at the MGP.

***Engineered in-situ treatment structures:*** Under certain conditions, in-situ funnel and gate structures can be used to direct seepage to a constructed in-situ groundwater treatment zone. However, all treatment materials have a limited life expectancy. If this limit is reached and ongoing groundwater treatment remains necessary, replacement of in-situ structures is costly and impractical. In addition, the installation of a grouted seepage barrier across Maori Tommy Gully has not proved efficient in redirecting or limiting seepage flows beneath the floor of the gully. Based on this experience, installing an effective funnel and gate system is likely to prove very difficult with no guarantee of success. Passive treatment is likely to be better achieved in a surface structure as discussed in later sections of this report.

***Partial lining of TTTSF:*** A partial lining of the TTTSF was evaluated to assess if seepage losses from the TTTSF could be reduced. Irrespective of how extensive the liner is, the same volume of tailings pore water and ongoing infiltration water would need to be managed on a long term basis. Installation of a partial or complete liner to the TSF would simply reduce seepage losses into the underlying rock mass and increase drainage system discharges. Closure of the drainage systems is unlikely to be an option due to the potential for geotechnical issues with the stability of the TSF embankment.

A partial liner is likely to have significant costs and would have limited effectiveness in reducing discharge flows and concentrations from the TTTSF. This option may have a place if a treatment plant were to be installed to reduce contaminant concentrations in the drainage water prior to discharge. The groundwater model of the TTTSF (Golder 2011a) indicates that the majority of the seepage water lost to the underlying bedrock discharges to relatively short sections of creek bed. If it becomes necessary to manage this component of the TTTSF discharges, it is likely to be simpler and more cost effective to install capped and sealed drainage systems in the stretches of the gullies receiving contaminated seepage.

***Extend Top Tipperary TSF underdrain system:*** Underdrain systems are planned to be installed in a few gullies within the TTTSF footprint. These drainage systems were simulated in the groundwater model of the TTTSF (Golder 2011a). Extension of these underdrains and the addition of further drains could potentially achieve two objectives:

- Reduce the loss of tailings pore water to the underlying rock mass, both over the short and long terms.
- Deliver the captured seepage water to a single discharge point, where it may be managed more effectively than could be achieved with diffuse seepage.

The installation of an extended drainage system at the base of the TTTSF is likely to reduce the time required from TTTSF closure for steady state groundwater conditions to be reached. This reduction does not necessarily translate to a reduction in the active management period during which discharge water is pumped to Frasers Pit. The larger discharge flows from an expanded underdrain system may require a longer period of active management before other means of discharge water management become viable. Expansion of the drainage system would not reduce the total volume of seepage water (or the contaminant load) that would discharge from the TTTSF over the long term.

## 5.2 Closure Stage Mitigation Options

### 5.2.1 Pump TSF decant and drain water to Frasers Pit for up to 20 years

Following closure of the MGP site, rehabilitation planning already assumes that remaining water in TSF decant ponds is pumped down and disposed of (Kingett Mitchell 2005). During the initial post-closure period it was expected that discharges from the TTTSF drain systems would be large and the water quality too poor to be directly released to Tipperary Creek or to be treated and released. The current post-closure MGP site management plan incorporates pumping of TSF decant and drain discharge water to Frasers Pit for an initial period of up to 10 years following closure of the TSF. The decant pond would be removed within a relatively short period. It is however uncertain exactly how long discharges would need to be pumped to Frasers Pit before other mitigation options could be instigated to ensure the discharges could be released to Tipperary Creek while complying with proposed water quality consent limits.

Modelling of the MGP water management system for the Macraes Phase III Project has incorporated base case assumptions that decant water from the TTTSF is pumped to Frasers Pit following closure and all TSF drainage discharges are pumped to Frasers Pit for a period of up to 20 years following closure of the MGP. Modelling of pit filling and evaporation rates indicate Frasers Pit is very unlikely to overflow within a 150 year period following closure of the site. The pumping of the TTTSF decant pond and TSF drain discharges to

Frasers Pit does not change this outcome. It is not clear from the modelling of this scenario that Frasers Pit lake would ever overflow.

With the exception of arsenic and sulphate, water quality criteria applicable for stock watering purposes are expected to be met in the Frasers pit lake. The conservative nature of the model is also likely to result in an over-estimation of contaminant concentrations in Frasers Pit lake (Section 7.0)

An aeration system and aerobic wetland could be installed for the purpose of removing iron and arsenic from the TSF water before it is discharged to Frasers Pit. The simulations of the Frasers Pit lake water quality do not however take into account removal of arsenic and iron by this means. Passive treatment of the TSF water prior to discharge to Frasers Pit or Frasers Underground mine could be expected to enable the pit lake water quality to meet ANZECC stock water guidelines for arsenic.

While sulphate concentrations may exceed stock watering limits within Frasers Pit, the lake is unlikely to be used for stock watering due to limited access created by steep pit slopes. For safety reasons alone, access to the lake would be restricted. If the use of the lake water for stock watering is considered an eventual goal for the pit lake, passive treatment methods as discussed in Section 4.2.2 could be implemented, potentially by placement of a BCR in the Frasers Underground. At this stage, treatment for sulphate is not included in the preferred suite of measures discussed in Section 7.0 because the costs of implementation are considered impractical compared to the benefit, since use of the pit lake for stock watering is considered unlikely. Diversion of TSF discharge flows to Frasers pit is a preferred option for managing downstream water quality because this option has the least impact on the wider area, internalises the effects of MIW discharges and allows potential effects to be managed through fencing and other land use controls.

Evaluation of the Frasers Pit lake water quality following closure has incorporated the effects of runoff from exposed pit walls and other surfaces within the pit catchment that cannot be effectively rehabilitated. Mine water discharges from the Frasers Underground to Frasers Pit following closure are expected to be small. These flows have not been incorporated in the evaluation of the pit lake water quality.

### 5.2.2 Permanent diversion of TTTSF discharges to Frasers Pit

An expansion of the water quality mitigation measure proposed in Section 5.2.1 takes into the account the assumption that drainage water from the TTTSF can be injected to the Frasers underground mine without pumping. This management concept is based on the installation of an engineered injection well from the proposed Tipperary sump down to the Frasers Underground mine workings and injecting all TTTSF drainage discharges and captured seepage flows upstream from the sump through this drill hole. The ground surface at the proposed sump location has an elevation of approximately 480 mRL, which is considerably higher than the projected water level in Frasers Pit at a date 150 years following closure (Figure 6). It is not clear from the modelling that Frasers Pit lake would ever overflow to the NBWR, even with the additional water from the TTTSF and the diversion of Frasers West WRS discharge diversion (refer Section 6.1.5) taken into account.

For modelling purposes it has been assumed that the drainage water is injected to the underground workings without pre-treatment. The quality of the water discharging from existing TSF drainage systems indicates the stored tailings are characterised by reducing geochemical conditions (Golder 2011h).

It is expected that the underground mine portal and ventilation shaft will be closed following the completion of mining operations and the atmosphere and accumulating water in the underground mine would subsequently become progressively more oxygen poor. In order to ensure the water injected to the underground workings remains under reducing conditions following injection, preparation of the receiving area may be undertaken prior to mine closure. It should be possible to load areas of the underground workings with constructed areas of media conducive to passive treatment (limestone, sacrificial iron and organic rich material) or alternatively inject organic-rich water into the constructed areas, thereby encouraging the water to remain under reducing conditions in the underground mine. In addition, management of the water quality should be able to encourage the production and precipitation of metal sulphides within the underground workings.

This preparation may include storage of organic material in the underground workings, which would react with the available oxygen following closure and thereby maintain the reducing environment. In addition, management of the water quality should encourage the production and precipitation of metal sulphides within the underground workings.

Under post-closure groundwater conditions the flow of water through the underground workings is expected to be very slow. On that basis the TSF water injected to these workings would have a long residence time and the water quality could be expected to stabilise during this period.

Iron and arsenic could potentially be removed from the drainage water to be injected to the underground workings using an aeration system combined with an aerobic wetland. Once injected, the water would gradually become oxygen poor and the hydrogeochemical conditions become more reducing with increasing distance from the injection point. This change could be enhanced, as discussed above, by preparing the receiving area in the underground workings using stored organic materials. With the correct preparation it should be possible to construct an anaerobic cell for sulphate removal in the underground workings, thereby reducing the sulphate concentrations projected to eventually develop in the pit lake.

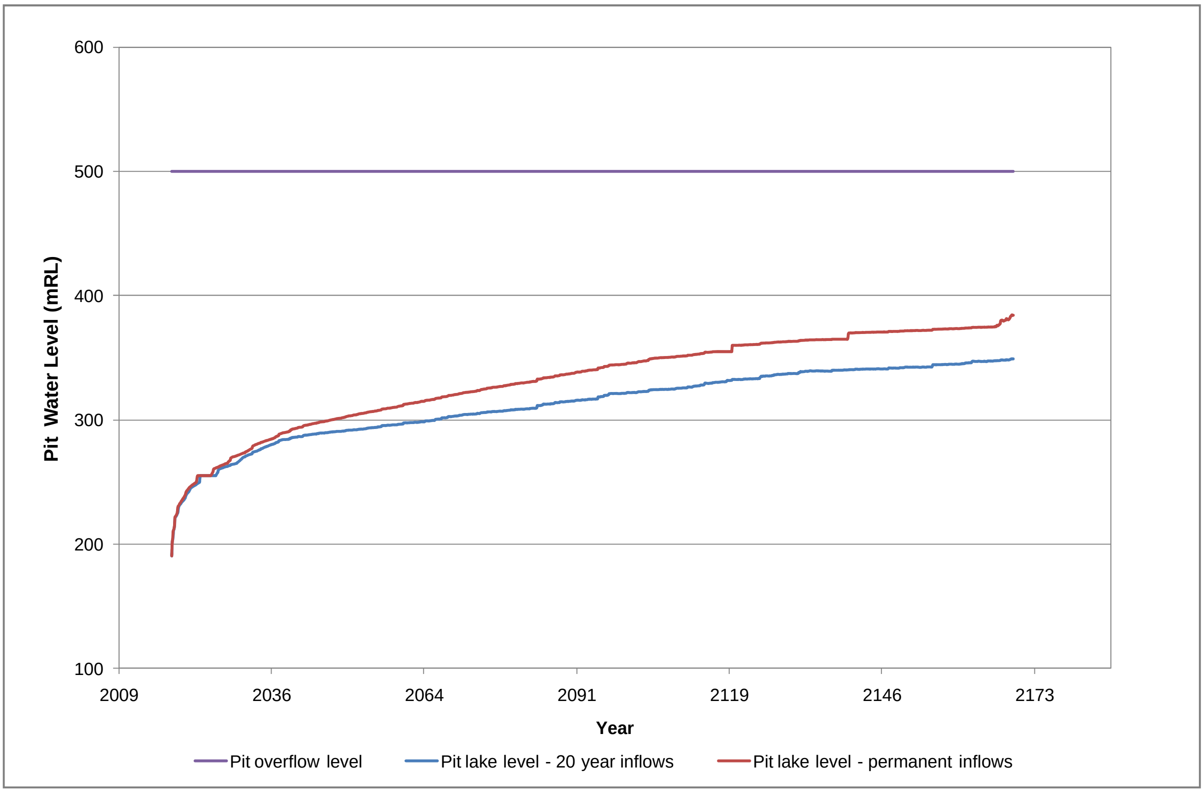



*Figure 6: Frasers Pit lake post-closure water level projections compared to the pit overflow level.*

Mine water discharges from the Frasers Underground to Frasers Pit following closure have not been incorporated in the evaluation of the pit lake water quality. The changes in water quality due to the passage of injected water past the exposed rock mass in the underground workings have not been evaluated. The uncertainties related to the eventual extent of the underground workings, flow paths within the workings, areas of collapsed rock and extent of mineralised rock exposed are too great to allow meaningful assessment. The potential for the injected water to take up additional iron, arsenic and sulphate from exposed rocks in the underground mine can be minimised through closing the access drives to mine stopes and panels prior to closure of the underground mine.

### 5.2.3 Creek base flow augmentation

A fresh water dam could be constructed in the Tipperary catchment to augment base flows in Tipperary Creek. The concept is for the dam to provide improved downstream water quality by lowering the risk of occurrence of critical low flows through the water course during the summer season.

Six scenarios involving a fresh water dam in the Tipperary catchment were identified as providing possible water quality mitigation options. Two scenarios have been tested by incorporation into variants of the site wide surface water model (Appendix D)

Scenario 1 incorporates a small fresh water dam (Figure 7) located a short distance downstream from the TTTSF embankment. This scenario has a very limited run-off catchment. Provided the storage volume for the dam is 600,000 $m^3$, which is the maximum available at this site, a constant release rate of approximately 2 L/s could be provided.

Scenario 2 incorporates a larger dam lower in the catchment (Figure 7), located on neighbouring property beyond the southern boundary of land owned by OceanaGold. The dam reservoir covers a maximum area of around 700,000 $m^2$ and fills to a maximum volume of around 22 $Mm^3$ before overtopping. The design height of the dam face is 75 m above the stream bed. On the basis of this design a constant release rate of approximately 29 L/s could be provided.

These simulation results indicate that a fresh water storage dam constructed on the main channel of Tipperary Creek tends to retain contaminants and release them over an extended period of time. This retention behaviour specifically applies to the conservatively transported contaminants such as sulphate. The model outcomes indicate neither of these two scenarios is likely to be suitable as a mitigation measure to ensure water quality compliance at TC01 and the Shag River at McCormicks.

### 5.2.4 Passive water treatment systems

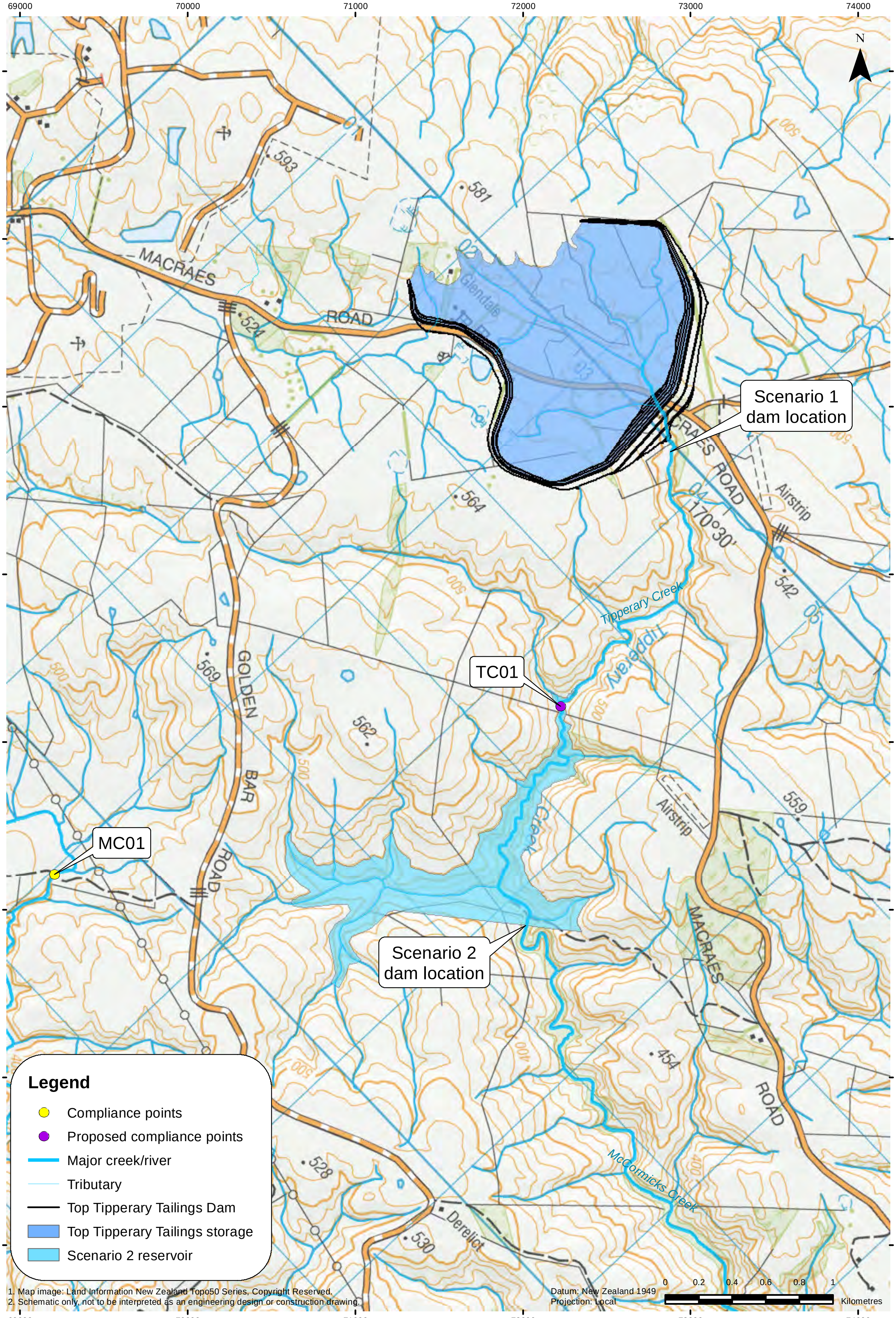
A passive water treatment system could be constructed to treat the combined drain and seepage water discharges from the TTTSF. Passive treatment, as described in Section 4.2.2, is a viable option for reducing contaminant concentrations in water sourced from a TSF. Treating the TSF drain and groundwater seepage discharges to reduce concentrations for arsenic and sulphate by 75% to 90% should enable ongoing compliance with the proposed water quality criteria at TC01. A staged treatment system for TSF discharge water (Section 4.2.2) is expected to be able to achieve sulphate and arsenic removal rates in the range required.

Modelled elevated concentrations of sulphate and arsenic at the McCormicks compliance point on the Shag River cannot however be addressed by mitigating discharges from the TTTSF alone. Passive water treatment of TTTSF discharges would need to be combined with effective management measures for discharges to Deepdell Creek. A suitable combination of measures should ensure the discharges are effectively mitigated to the water quality criteria applicable at McCormicks on the Shag River. As discussed in Section 5.2.2, there is the opportunity to pass drainage water from the TTTSF through an aerobic wetland before it could be injected into the Frasers Underground mine. This process would be expected to substantially reduce the concentrations of arsenic and iron in the injected water. An improvement in injected water quality could reduce the effects of injecting the drainage water on the long term water quality in Frasers Pit lake.

## 6.0 WRS MITIGATION OPTIONS

### 6.1.1 Low permeability WRS

Current rehabilitation planning for the WRS's incorporates the placement of soil on top of the waste rock. One of the objectives is to reduce rainwater infiltration to the equivalent of the regional recharge rate of 32 mm/year. Based on on-site observations of underdrain discharge flow rates and the lack of springs developing along the toe of existing WRS's, it appears likely that this objective is being achieved.

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As described for TSF capping, it is unlikely that a lower recharge rate to stored waste rock could be achieved through simply applying a low permeability cap using materials available at the site. Constructing an impermeable cap using geotextiles or other forms of artificial covering material could potentially reduce the rate of infiltration. Capping WRS's in this manner would however be an expensive project, which would also result in other rehabilitation issues, including:

- Maintenance – the requirement of regular maintenance for capping materials.
- Dying off of Vegetation - the wetting and drying cycle in the soils overlying the cap would be more extreme than in those across the remainder of the site. Major rainfall events could lead to soil saturation while the summers would probably be characterised by extended periods of parched soils. The limited rooting depth would limit vegetation capacity to access moisture in deeper soils.
- Erosion - run-off erosion can lead to exposure of the cap's impermeable layer, with the attendant risk of damage.
- Restriction on land uses - potential post-closure land use options of the capped surface are limited by the above issues.

These issues limit the practical viability of low permeability caps to reduce the leaching of contaminants form WRS's at the site.

### 6.1.2 Run-off infiltration drains downstream from WRSs

The MGP area is characterised by rapid run-off of rainfall. One option to reduce the down-gradient concentration of contaminants is to encourage infiltration of run-off water into the plumes down-gradient from the WRSs. Groundwater discharges down-gradient from the infiltration zones could be expected to increase if this option is implemented, however the mass load would be the same. In effect, the enhanced infiltration of rainwater is one means by which the base flow in the receiving creeks and tributaries could be increased.

Rather than capturing runoff using a surface dam and using this water to dilute the contaminated groundwater discharges into the local creeks during low flow periods, this is achieved by diffusing the run-off water into infiltration basins. Data obtained from water quality monitoring at the groundwater monitoring wells along the NBWR suggests the Frasers West silt dam may already be acting as an infiltration basin.

### 6.1.3 Evaporation basins for WRS runoff and seepage

Should underdrains be installed beneath the WRSs the issue of managing this water over the long term would remain. Capture of this groundwater seepage is only of value if the quality of the discharge water can be improved or the volume of water discharged can be reduced.

One option for volume reduction, especially during periods of soil moisture deficit, is to irrigate the water to areas of pasture that can be used as an evaporation surface. The evaporation system can essentially be installed using surface drains linked to the WRS underdrains or to the silt dams downstream from the WRS's.

Installation costs are relatively low, however ongoing monitoring would need to be undertaken to ensure the soil quality is not degraded to the extent that the efficiency of the evaporation zone is affected. Long term management of the evaporation zones may be necessary.

### 6.1.4 Passive treatment

Passive treatment systems could be established at or down-stream from WRS silt ponds to reduce sulphate loads to the nearby creeks. These systems would be focused on management of groundwater discharges to gullies down-gradient from the WRSs. Surface run-off from the WRS's and surrounding areas would need to be diverted away from the treatment plant intakes. Long-term monitoring and management of the passive treatment systems would be necessary to ensure contaminant removal efficiency is maintained.

The size of passive treatment systems suitable to manage water quality in WRS discharges is relatively small. Ongoing monitoring and eventual maintenance costs are likely to limit the usefulness of these systems for mitigation purposes.

### 6.1.5 Groundwater intercept drains

Diversion of the shallow groundwater flows from around the toe of the Frasers West WRS into Frasers Pit on a permanent basis offers a potential water quality management option for the NBWR. Review of the topography and hydraulic gradients close to the base of the Frasers West WRS indicates it is feasible to construct a drainage system to capture shallow groundwater down-gradient from the Frasers West WRS in the NBWR catchment.

Additionally, installation of a drain around the southern side of the proposed Frasers South WRS with a discharge to existing backfill in the Golden Ridge Pit (Southern extension of Frasers Pit) should limit new net effects on the water quality of the Murphys Creek catchment. The ground surface immediately upstream from the Murphys Creek silt pond is at an elevation of approximately 440 mRL, which is above the projected water level in Frasers Pit at a date 150 years following closure (Golder 2011c). Review of the topography and hydraulic gradients close to the base of the Frasers South WRS indicates it is feasible to construct a drainage system to capture shallow groundwater down-gradient from the Frasers South WRS in the Murphys Creek catchment.

Simulations of the mine water management system incorporating diversion drains redirecting surface water and groundwater discharges from WRS's and the TTTSF to Frasers Pit have been undertaken. The outcomes from these simulations indicate water quality in the Frasers Pit lake would exceed the ANZECC stock watering guidelines for arsenic and sulphate unless mitigation measures were instigated. As previously discussed (Section 5.2.1), passive treatment for arsenic would enable the pit lake water to comply with the stock drinking water guidelines. At this stage mitigation, for sulphate in the lake water is not considered necessary.

# 7.0 COMPARISON OF OPTIONS

## 7.1 Introduction

The preferred mitigation approach involves implementing a suite of measures that are effective in meeting water quality goals, feasible to implement concurrent with mining operations, have reasonable capital costs, and require little to no active maintenance following closure of the mine. A modifying consideration is also the resource consenting issues that implementation of the mitigation measures themselves create.

The effectiveness of any single mitigation measure is primarily measured by the extent of compliance with the proposed arsenic and sulphate compliance limits following installation. For comparison, a summary of the predicted changes in water quality linked to the mitigation scenarios simulated using the site wide water management model is presented in Appendix F.

## 7.2 Screening of Options

A summary of the outcomes from screening of the identified mitigation options as they pertain to operational versus closure stages for the Deepdell Creek catchment and the Tipperary Creek catchment is provided in Table 3 to Table 6. Further, consideration of WRS seepage mitigation for the Murphys Creek and NBWR catchments is summarised in Table 7 (operational stages) and Table 8 (post-closure stage). These tables identify options as being preferred, retained or eliminated on the basis of the criteria presented in Table 2.

**Table 2: Mitigation option assessment terminology.**

| Descriptor | Definition of term. |
|---|---|
| Preferred | Option is identified as practical and effective. |
| Retained | Option is considered to be a possible alternative for implementation, subject to adaptive management over the life of mine. |
| Eliminated | Option is eliminated due to ineffectiveness or lack of applicability to the site. |

## 7.3 Evaluation of Preferred Combination of Options

A mine water management simulation has been undertaken to understand the level of compliance that could be achieved taking into account the following preferred mitigation measures:

- Diversion of MTI drain discharges to Frasers Pit for a period of up to 20 years following closure. Installation of an aerobic passive treatment system to remove up to 90% of the arsenic and iron from the MTI drainage water prior to discharge to the pit lake.
- Installation of an aerobic passive treatment system in or close to Maori Tommy Gully to remove up to 90% of the arsenic and iron from the MTI drainage water.
- Installation of a fresh water dam on Camp Creek. As discussed in Section 4.2.1, it expected that a constant discharge from Camp Creek of 10 L/s should be sufficient to manage and effectively mitigate sulphate concentrations in Deepdell Creek and in the Shag River as far as the confluence with McCormicks Creek. If necessary however a discharge rate of 16 L/s, achieved through managed release, could be achieved.
- Removal of the Maori Tommy Gully silt dam.
- Directing TTTSF drain discharges and groundwater seepage upstream from the Tipperary Sump into a wetland prior to injection to the Frasers underground mine.
- Diversion of surface water run-off and a proportion of groundwater seepages from the Frasers West and Frasers South WRS's to Frasers Pit.

In terms of water volumes and water levels in Frasers Pit, the model indicates the pit would not overflow within the modelled 150 year post-closure period (Figure 6). This combination of measures is projected to achieve effective compliance with the water quality criteria proposed for the compliance points around the MGP (Appendix E).

The permanent diversion of TTTSF drain discharge water to the Frasers Underground mine is expected to result in an increase in the long term concentrations of sulphate in the Frasers Pit lake. If this mitigation measure was not implemented it could be expected that the concentrations of sulphate in the pit lake would over time decrease to below the ANZECC stock drinking water guideline. Ongoing injection of the TTTSF drain discharges to the underground mine is likely to result in the sulphate concentrations in the pit lake not meeting the ANZECC guideline.

## 7.4 Comprehensive Monitoring Program

A level of uncertainty is associated with the model projections. To confirm projections for long-term compliance with water quality criteria following mine closure, further monitoring and investigation of water quality trends, absorption processes, process water management options and the performance of proposed mitigation measures is required. A water management plan for Macraes Phase III would involve ongoing monitoring of water quality at critical points. The accumulated data would be used to confirm projected trends in water chemistry including the assumed model conservatism.

**Table 3: Mitigation options screening for Deepdell Creek and Shag River compliance points – operational period.**

| Mitigation option | Effectiveness | Ease of implementation | Cost factors | Comment | Prefer / retain / eliminate |
|---|---|---|---|---|---|
| Pump Back Road WRS groundwater seepage to MWM system | Reduce compliance risk during very low flow periods. | Would require construction of interceptor structures for WRS groundwater seepage and potentially runoff | Construction costs, pumps, electricity, maintenance. | Only if monitoring results indicate unanticipated exceedances at compliance points. | Retained |
| Camp Creek or Highlay Creek freshwater dam | If dam constructed during operational period, water could be used to supplement process water supplies if release of TSF drain discharges undertaken during high creek flows. Also an option for post-closure water quality mitigation. | Dam could be readily constructed using available materials and incorporated in mine operations. | Capital costs associated with design and construction of dam and associated infrastructure. Relatively low maintenance costs. | New concept for stakeholders. | Preferred |
| Camp Creek or Highlay Creek freshwater dam with augmentation from Taieri | With flow augmentation could ensure achieve 100% compliance at the Shag River. Stored water could be used to supplement process water supplies if release of decant water is undertaken during high flows. | Dam could be readily constructed using available materials. | Capital costs associated with design and construction of dam and associated infrastructure. Maintenance costs. | Only if monitoring results indicate unanticipated exceedances at compliance points. | Retained for operational mine period only |

**Table 4: Mitigation options screening for Deepdell Creek and Shag River compliance points – post closure.**

| Mitigation option | Effectiveness | Ease of implementation | Cost | Comment | Prefer / retain / eliminate |
|---|---|---|---|---|---|
| Pumping TSF drain discharge and groundwater seepage to Frasers Pit – up to 20 years post-closure. | Effective means of removing TSF chemistry from Deepdell Creek. Some groundwater seepage may be difficult to capture. | Relatively easy to pump water from MTG silt pond to Frasers Pit. | Pumps, electricity, maintenance. | Acceptable within current consents. | Preferred |
| Camp Creek or Highlay Creek freshwater dam | Camp Creek dam sufficient for effective mitigation. Highlay Creek dam less effective. Long-term maintenance is required. | Dam could be readily constructed using available materials and incorporated in mine operations. No requirement for active pumping. | Capital costs associated with design and construction of dam and associated infrastructure. Relatively low maintenance costs. | New concept for stakeholders. | Preferred |
| Camp Creek or Highlay Creek freshwater dam with augmentation from Taieri | With flow augmentation could ensure achieve 100% compliance at the Shag River. | Dam could be readily constructed using available materials. More difficult to implement over long term due to requirement for maintaining active pumping system. | Capital costs associated with design and construction of dam and associated infrastructure. Long-term maintenance and operations costs due to active pumping. | Involves long-term abstraction from Taieri River. | Eliminated |
| Deepdell Creek freshwater dam without augmentation | Discharges likely to meet compliance criteria. Long-term maintenance is required. | Dam could be readily constructed using available materials. Low long-term maintenance costs. | Substantial capital costs associated with design and construction of dam and associated infrastructure. Relatively low maintenance costs. | Preliminary consultation with ORC concerned with ecological effects indicated a freshwater dam on Deepdell Creek should be avoided. | Eliminated due to effects on galaxiids and construction difficulties. |

| Mitigation option | Effectiveness | Ease of implementation | Cost | Comment | Prefer / retain / eliminate |
|---|---|---|---|---|---|
| Pumping from Lone Pine Reservoir to Deepdell Creek | Sufficient flows were not achievable from Lone Pine reservoir to make this option viable. | N/A | N/A | N/A | Eliminated |
| Passive treatment at TSF's (drain and groundwater seepage) | Post-closure flows are likely to be treatable by passive treatment. Long-term maintenance is required. | A passive treatment system (PTS) can be constructed with available materials. Long-term maintenance is minimal. If sulphate mitigation is the objective periodic (estimated 20 year intervals) removal and disposal of media in biological reactor required. | Capital costs associated with design and construction of treatment cells. Relatively low maintenance costs. Costs highly dependent on flow rates, objectives of treatment and demand for sacrificial iron for reduction of sulphate. | Use of passive treatment systems has been part of previous consents. Arsenic and sulphate have been effectively treated using passive treatment systems elsewhere therefore the technology should be considered acceptable by stakeholders. | Preferred for arsenic and iron removal. Retained for sulphate removal although not preferred due to availability of other options at lower costs. |
| Passive treatment of runoff and groundwater seepage from WRS's | Post-closure flows are likely to be treatable by passive treatment. Long-term maintenance is required. | A passive treatment system (PTS) can be constructed with available materials. Infrastructure such as interceptor trenches would be required to capture WRS seepage. Long-term maintenance is minimal but periodic (estimated 20 year intervals) removal and disposal of media in biological reactor will be required. | Capital costs associated with design and construction of treatment cells and pipelines. Relatively low maintenance costs. Costs highly dependent of flow rates and requirement for use of sacrificial iron for reduction of sulphate. | Use of passive treatment systems in this role have not been part of previous consents. Arsenic and sulphate have been effectively treated using passive treatment systems therefore the technology should be considered acceptable by | Retained as an alternative for iron removal. Retained for sulphate removal although not preferred due to availability of other options at lower costs. |

| Mitigation option | Effectiveness | Ease of implementation | Cost | Comment | Prefer / retain / eliminate |
|---|---|---|---|---|---|
| | | | | stakeholders. | |
| Low permeability cap on MTI, SPI or WRSs | Capping would eliminate infiltration of precipitation into TSF's or WRS's which theoretically limits leaching. Degree of infiltration is limited in uncapped WRS's due to evaporation and use of finer grained conventional cover. Groundwater which flows through TSFs and WRSs from up-gradient sources would not be limited through capping. Long-term maintenance is required. | Capping materials could consist of clay, geotextiles, geofabrics, cushion sands, etc. Capping materials are readily available but may require transport from relatively long distances from the site. A significant amount of materials would be required to cap both TSF's and WRS's. Long-term use of capped surfaces severely restricted. | Capital costs for caps tend to be high. Costs to periodically inspect and repair cap would be relatively low but ongoing. Land use restriction limits long term value of rehabilitated land. | Currently no modelling of caps has been undertaken due to the likely presence of groundwater seepage that would not be mitigated by capping. | Eliminated due to limited effectiveness in relation to anticipated costs. |
| Removal of Maori Tommy Gully silt pond | Not effective alone but in combination with other technologies may help in reducing maximum concentrations during low flows. | Once the TSF and WRS closure plans have been implemented, the need for the silt pond will be eliminated and removal of the silt pond could be readily implemented. | The costs for removal of the MTG silt pond would be relatively low. | Relatively straight-forward provided silt pond no longer necessary for silt management. | Preferred |

**Table 5: Mitigation options screening for Tipperary Creek and Shag River compliance points – operational period.**

| Mitigation option | Effectiveness | Ease of implementation | Cost | Comment | Prefer / retain / eliminate |
|---|---|---|---|---|---|
| Partial low permeability liner across base of TTTSF | A partial low permeability liner would direct a component of flows from groundwater seepage to drain seepage but the mass of contaminants to be mitigated would not be reduced. | Geotextile liner would be necessary. Installation difficult due to terrain. | Cost of design and construction is likely to be high. | | Eliminated due to minimal effectiveness. |
| Full low permeability liner at TTTSF | A full low permeability liner would direct all infiltrating water to drains rather than having water exit system via groundwater seepage. A full TSF liner would also minimise inflow of groundwater from up-gradient. The mass of contaminants exiting the system would be similar but the flows may be decreased. | Geotextile liner would be necessary. Installation difficult due to terrain. Difficult to determine if breaches occur over time. | Cost of design and construction is likely to be high. | | Eliminated as discharge water still needs to be managed. Option not effective alone. |

**Table 6: Mitigation options screening for Tipperary Creek and Shag River compliance points – post-closure.**

| Mitigation option | Effectiveness | Ease of implementation | Cost | Comment | Prefer / retain / eliminate |
|---|---|---|---|---|---|
| Pump TTTSF drains and groundwater seepage to Frasers Pit for up to 20 years | Effective means of removing TSF chemistry from Tipperary Creek and Shag River. Some groundwater seepage may be difficult to capture. | Relatively easy to pump water from TTTSF silt pond to Frasers Pit | Pumps, electricity, maintenance | Acceptable within current consents. | Preferred |
| Inject water to Frasers Underground on long-term basis. | Effective at meeting compliance limits at TC01 and Shag River. | Drilling and installation of casing should be relatively straight forward. | Moderately low CAPEX costs. Low long-term costs. | Acceptable within current consents. | Preferred |
| Tipperary Creek freshwater dam, upstream location. | Not effective alone. If combined with passive treatment of TSF discharges or augmentation with water from Taieri, is likely to meet compliance criteria at TC01 and Shag River. Long-term maintenance is required. | Dam could be readily constructed using available materials. Supplementary treatment or inflow augmentation introduce more implementation issues. | Capital costs associated with design and construction of dam and associated infrastructure. Long-term maintenance costs from supplementary processes | Preliminary consultation with ORC indicated a freshwater dam on Tipperary Creek would be acceptable. Requires long-term abstraction from Taieri may be difficult to consent. | Eliminated as not effective alone. |
| Tipperary Creek freshwater dam, downstream location | Not effective alone. If combined with passive treatment of TSF discharges or augmentation with water from Taieri, is likely to meet compliance criteria at TC01 and Shag River. Long-term maintenance is required. | Dam location on neighbouring property. Property purchase may be an obstacle. Dam could be readily constructed using available materials. | Capital costs associated with design and construction of dam and associated infrastructure. Would include cost of neighbouring property. Long-term maintenance costs from supplementary processes | Preliminary consultation with ORC indicated a freshwater dam on Tipperary Creek would be acceptable. Long-term abstraction from Taieri may be difficult to consent. | Eliminated as not effective alone. |

| Mitigation option | Effectiveness | Ease of implementation | Cost | Comment | Prefer / retain / eliminate |
|---|---|---|---|---|---|
| Freshwater dam on western tributary of Tipperary Creek. | Possibly effective alone, although more investigation work required. | Dam could be readily constructed using available materials. | Capital costs associated with design and construction of dam and associated infrastructure. | Preliminary consultation with ORC indicated a freshwater dam on Tipperary Creek would be acceptable. | Eliminated as not as practical as rerouting TTTSF discharges to Frasers Underground. |
| Passive treatment at TSFs (drain and groundwater seepage) | Post-closure flows are likely to be treatable by passive treatment. Long-term maintenance is required. Discharge flows from plant become dilution water for other contaminant sources. | A passive treatment system can be constructed with available materials. Long-term maintenance is minimal but periodic (estimated 20 year intervals) removal and disposal of media in biological reactor will be required. | Substantial capital costs associated with design and construction of treatment cells. Relatively low maintenance costs. Costs highly dependent of flow rates and requirement for use of sacrificial iron for reduction of sulphate. | Use of passive treatment systems in this role has not been part of previous consents. Arsenic and sulphate have been effectively treated using passive treatment systems therefore the technology should be considered acceptable by stakeholders. | Preferred for removal of arsenic and iron. Non-preferred for removal of sulphate due to availability of other options at lower costs. May be considered in future. |
| Low permeability cap on TTTSF | Capping would eliminate infiltration of precipitation into TTTSF, and following final drainage of decant water would theoretically limit leaching. Groundwater which flows through TTTSF from up-gradient sources would not be limited through capping. Long-term maintenance | Capping materials could include clay, geotextiles, geofabrics, cushion sands, etc. Capping materials are readily available but may require transport from relatively long distances from the site. A significant amount of materials would be required to cap the | Capital costs for caps tend to be high. Costs to periodically inspect and repair cap would be relatively low, but ongoing. Land use restriction limits long term value of | Currently no modelling of caps has been undertaken due to the likely presence of groundwater seepage that would not be mitigated by capping. | Eliminated due to limited effectiveness in relation to anticipated costs. |

| Mitigation option | Effectiveness | Ease of implementation | Cost | Comment | Prefer / retain / eliminate |
|---|---|---|---|---|---|
| | is required. | TTTSF. Long-term use of capped surfaces severely restricted. | rehabilitated land. | | |
| Full encapsulation of TTTSF | A combination with a low permeability liner and cap would provide a system which minimises inflow and outflow of water from the TTTSF. The decant water would need to be allowed to drain from the system for years following closure but when fully evacuated the drains could be sealed. Achieving full encapsulation could be challenging. | Impermeable materials could be placed at the base, sides and top of the TTTSF during construction. Would need geotextiles that are readily available. Installation difficult due to topography. Achieving and demonstrating low permeability goals during construction may be difficult. Difficult to determine if breaches occur over time. | Capital costs for encapsulation materials, design and construction very high. Costs to periodically inspect and repair cap would be relatively low, but ongoing. Land use restriction limits long term value of rehabilitated land. | If encapsulation could be demonstrated to effectively limit flow of impacted water to the nearby streams it would likely be accepted by stakeholders. | Eliminated due to high costs when other more cost effective options are available. |

**Table 7: Mitigation options screening for Murphys Creek and North Branch Waikouaiti River compliance points – operational period.**

| Mitigation option | Effectiveness | Ease of implementation | Cost | Comments | Prefer / retain / eliminate |
|---|---|---|---|---|---|
| Pump WRS runoff and groundwater seepage to Frasers Pit | Effective means of removing WSR chemistry from NBWR. Some groundwater seepage may be difficult to capture. | No infrastructure is currently in place to capture WRS runoff and groundwater seepage except silt ponds. Additional infrastructure may be needed. | Capital cost would be associated with any new infrastructure required. Ongoing costs of maintenance and electricity would be required during operations. | Acceptable within current consents. | Preferred |
| Low permeability cap on WRS when completed. | Would reduce effects of "impacted run-off" from WRS and reduce groundwater seepage losses. | Capping materials could include clay, geotextiles, geofabrics, cushion sands, etc. Capping materials are readily available but may require transport from relatively long distances from the site. A significant amount of materials would be required to cap the WRS. Long-term use of capped surfaces severely restricted | Capital costs for caps tend to be high. Costs to periodically inspect and repair cap would be relatively low, but ongoing. | Currently no modelling of caps has been undertaken due to the likely presence of groundwater seepage that would not be mitigated by capping. | Eliminated due to limited effectiveness in relation to anticipated costs. |
| Covered evaporation basins for WRS runoff and groundwater seepage | If evaporation basins can be sized and designed to prevent runoff and groundwater seepage from discharging to NBWR and Murphy's Creek, mitigation would be effective. No detailed assessment or testing of this technology has been undertaken. Evaporation basis would need to be covered. | Preliminary assessment of required basin sizes has been undertaken and suggests land available could be sufficient to allow for basins. Easy to construct with available materials. A design would need to be developed and tested. | Design and construction costs for evaporation basins estimated to be moderate. Ongoing cost of maintenance would be relatively low. Periodic removal and disposal of sludge would be required and have | Similar to pumping water to Frasers Pit and therefore likely to gain stakeholder approval. | Eliminate Non-preferred due to availability of other options at lower costs. May be considered in future. |

| Mitigation option | Effectiveness | Ease of implementation | Cost | Comments | Prefer / retain / eliminate |
|---|---|---|---|---|---|
| | | | associated costs. | | |
| Increase infiltration of surface run-off to groundwater. | Potentially effective if impacted water can be sufficiently diluted by increased groundwater recharge. Concept needs to be further developed and tested to determine full effectiveness. Innovative. | Infiltration basins probably viable but require on-going maintenance. | Design and construction cost are dependent of complexity of system required. Maintenance. | Innovative concept so stakeholders would need further documentation of effectiveness. Would not deplete surface water body inflows. | Non-preferred. Potentially consider in future if further assessment suggests benefit. |

**Table 8: Mitigation options screening for Murphys Creek and North Branch Waikouaiti River compliance points – post-closure.**

| Mitigation option | Effectiveness | Ease of implementation | Cost | Consenting | Preferred / Non-preferred |
|---|---|---|---|---|---|
| Interception drains for shallow groundwater down-gradient from the Frasers West WRS in the NBWR catchment with discharge to Frasers Pit. | Effective mitigation to compliance limits in NBWR. | Conventional construction methods. Primary issue is in ensuring capture system operates under gravity flow. | Estimated to be moderate. | Probably acceptable within current consents. | Preferred |
| Interception drain around the southern side of the proposed Frasers South WRS with discharge to the existing backfill in the Golden Ridge Pit (Southern appendix of Frasers Pit). | No net effects on the water quality of the Murphys Creek catchment. | Conventional construction methods. Primary issue is in ensuring capture system operates under gravity flow. | Estimated to be moderate | Probably acceptable within current consents | Preferred |
| Freshwater dam on | Possibly effective alone, although | Dam could be readily | Capital costs | | Non-preferred. |

| Mitigation option | Effectiveness | Ease of implementation | Cost | Consenting | Preferred / Non-preferred |
|---|---|---|---|---|---|
| Murphys Creek upstream of MCI. | more investigation work required. | constructed using available materials. | associated with design and construction of dam and associated infrastructure. | | Consider in future as substitute for diversion of discharges to Frasers Pit. |
| Low permeability cap on WRS when completed. | Would reduce effects of “impacted run-off” from WRS and reduce groundwater seepage losses. | Capping materials could include clay, geotextiles, geofabrics, cushion sands, etc. Capping materials are readily available but may require transport from relatively long distances from the site. A significant amount of materials would be required to cap the WRS. Long-term use of capped surfaces severely restricted | Capital costs for caps tend to be high. Costs to periodically inspect and repair cap would be relatively low, but ongoing. | If construction of a cap could be demonstrated to allow compliance with surface water quality criteria it would likely be accepted by stakeholders. Currently no modelling of caps has been undertaken due to the likely presence of groundwater seepage that would not be mitigated by capping. | Eliminated due to limited effectiveness in relation to anticipated costs. |
| Covered evaporation basins for WRS runoff and groundwater seepage | If evaporation basins can be sized and designed to prevent runoff and groundwater seepage from discharging to NBWR and Murphy’s Creek, mitigation would be effective. No detailed assessment or testing of this technology has been undertaken. Evaporation basis would need to be covered. | Preliminary assessment of required basin sizes has been undertaken and suggests land available could be sufficient to allow for basins. Easy to construct with available materials. A design would need to be developed and | Design and construction costs for evaporation basins estimated to be moderate. Ongoing cost of maintenance would be relatively low. Periodic removal and disposal | Similar to pumping water to Frasers Pit and therefore likely to gain stakeholder approval. | Retained. Non-preferred due to availability of other options at lower costs. |

| Mitigation option | Effectiveness | Ease of implementation | Cost | Consenting | Preferred / Non-preferred |
|---|---|---|---|---|---|
| | | tested. | of sludge would be required and have associated costs. | | |
| Increase infiltration of surface run-off to groundwater. | Potentially effective if impacted water can be sufficiently diluted by increased groundwater recharge. Concept needs to be further developed and tested to determine full effectiveness. Innovative. | Infiltration basins probably viable but require on-going maintenance. | Design and construction cost are dependent of complexity of system required. Maintenance. | Innovative concept so stakeholders would need further documentation of effectiveness. Would not deplete surface water body inflows. | Eliminated due to long term maintenance requirements. |
| Passive treatment of runoff and groundwater seepage from WRS's | Post-closure flows are likely to be treatable by passive treatment. Long-term maintenance is required. | A passive treatment system (PTS) can be constructed with available materials. Infrastructure such as interceptor trenches would be required to capture WRS seepage. Long-term maintenance is minimal but periodic (estimated 20 year intervals) removal and disposal of media in biological reactor will be required. | Capital costs associated with design and construction of treatment cells and pipelines. Relatively low maintenance costs. Costs highly dependent of flow rates and requirement for use of sacrificial iron for reduction of sulphate. | Use of passive treatment systems in this role have not been part of previous consents. Arsenic and sulphate have been effectively treated using passive treatment systems therefore the technology should be considered acceptable by stakeholders. | Preferred for possible removal of iron and arsenic. Retained for sulphate removal although not preferred due to availability of other options at lower costs. |

As discussed throughout the surface water management model (Golder 2011c) and this report, the surface water model has been developed based on conservative assumptions and without incorporation of likely attenuation factors for contaminants such as arsenic and iron. Development of model runs which project water quality for a preferred suite of mitigation measures has been undertaken to create confidence that compliance with water quality goals is achievable. However, instigation of specific measures would only be undertaken if measured water quality trends indicate compliance limits would likely be exceeded. Implementation of a comprehensive monitoring program is therefore an essential part of the water management strategy.

## 7.5 Recommended Compliance Limits

Compliance limits have been proposed for the Macraes Phase III Project which are consistent with current consents for the wider MGP (Golder 2011c).

The water management plan for the Macraes Phase III Project is to include an adaptive management approach to maintain water quality at surface water compliance points within consented compliance limits. Further water quality management options, additional or alternative to those considered appropriate at this stage, exist and are expected to be evaluated prior to mine closure as part of this adaptive management approach.

This approach to water quality effects management provides OceanaGold with the flexibility to adapt and optimise mitigation options which are considered likely to be effective and therefore provide confidence to project stakeholders. During design of the water management plan further consideration and refinement of the proposed measures is expected to be undertaken.

# 8.0 SUMMARY

An integrated water management model (Golder 2011c) has been used to generate water quality projections for current and proposed surface water compliance points associated with the MGP. The model produces projections of contaminant concentrations covering the operational period of the mine and a 150 year post-closure period. Compliance criteria developed for existing Resource Consents, or proposed compliance criteria, have been compared with projected surface water concentrations for each major catchment intersecting the MGP. Water management measures are expected to be required to ensure compliance with the existing and proposed criteria.

The primary issues for water quality compliance are sulphate, arsenic and iron. Sulphate is less likely to become naturally attenuated in the surface water system than other contaminants. Mitigation is therefore focused primarily around ensuring effective compliance with the sulphate criteria is achievable.

The effectiveness of a variety of water quality mitigation options has been assessed at a screening and initial simulation level, taking into account the practicality of implementation of these options and input from various project stakeholders. The results indicate an appropriate mitigation approach is to combine a suite of measures to address projected water quality issues in the receiving water bodies around the MGP.

The proposed mitigation strategy involves the use of standard adaptive management approaches. The strategy is based on meeting the receiving environment criteria for water quality and demonstrating how compliance could be achieved using the proposed suite of measures but not fixing proposed management and mitigation options. This approach sets the receiving environment criteria and assesses compliance projected to be achieved by a range of options but also assesses options against economic and technical feasibility considerations. Following the assessment of options a range of measures considered appropriate has been adopted for implementation. These measures are subject to adaptive management changes following ongoing monitoring, investigation and bench scale studies and testing of treatment technologies.

The mitigation strategy which has been developed can be summarised in accordance with the following four points:

**Mitigation measures during operational period:** OceanaGold is to continue to implement mitigation measures which are required under current Resource Consents throughout the operational period of the Macraes Phase III Project. Implementation of the water quality management options listed below should enable OceanaGold to continue to meet the receiving environment criteria for water quality for the operational phase of mining:

- Pumping all captured discharges from TSF and WRS areas to the mine water management system, as required by current consents. The effectiveness of this measure at Deepdell Creek and the Shag River has been demonstrated in practice through results from the site environmental monitoring program, where non-compliance events have been minimal.
- Construction of drains to intercept shallow groundwater down-gradient from the Frasers West WRS in the NBWR catchment and pumping the collected water back to the mine water management system, and
- Construction of an interception drain around the southern side of the proposed Frasers South WRS and pumping the collected water back to the mine water management system.

**Mitigation measures during post closure period:** A suite of measures has been identified that is considered appropriate to effectively mitigate potential water quality issues associated with the Macraes Phase III Project and also the wider MGP following closure of the site. These measures include:

- Pumping of TSF discharges to Frasers Pit for up to 20 years following closure of each facility to allow discharge flow rates to decrease to the point where other passive mitigation measures (specified below) could be instigated. Once effective passive mitigation measures have been instigated, pumping of TSF discharges to Frasers Pit would cease.
- of an aerobic passive treatment system in or close to MTG to remove up to 90% of the arsenic and iron from the MTI drain discharges once the flow rates have decreased to the extent that these discharges can be released. Removal of Maori Tommy Gully silt dam.
- Construction of a fresh water dam on Camp Creek to provide a base flow to Deepdell Creek to manage and effectively mitigate sulphate concentrations in Deepdell Creek and in the Shag River as far as the confluence with McCormicks Creek. If necessary, seasonal or flow matched discharges of water may be provided from the proposed Camp Creek dam to effectively mitigate the sulphate concentrations in the Shag River. The actual discharge regime needed to effectively mitigate for the MGP discharges should be determined on an adaptive management basis once monitoring improves our understanding of what concentrations of contaminants and discharge flows from the TSF's eventually need to be managed.
- Passive injection of drainage water and captured groundwater seepage from the TTTSF to the Frasers underground mine. This measure would enable compliance with water quality criteria in Tipperary Creek and assist in compliance with the criteria applicable on the Shag River at McCormicks on a long term basis.
- Continued operation of interception drains for shallow groundwater down-gradient from the Frasers West WRS in the NBWR catchment with collected water to be discharged to Frasers Pit.
- Continued operation of an interception drain around the southern side of the proposed Frasers South WRS with collected water to be discharged to the existing backfill in the Golden Ridge Pit (Southern extension of Frasers Pit), and
- If management or mitigation of iron, arsenic and $cyanide_{WAD}$ concentrations in the Frasers Pit lake is required, this could be achieved through the construction of aerobic passive treatment systems to remove arsenic, iron and $cyanide_{WAD}$ from water pumped to this lake or injected into the underground workings. The same measure could potentially be applied to manage seepage discharges to the Round Hill pit lake. Although this measure is not necessary to enable compliance with water quality

criteria downstream from the MGP, it would lead to improvement in the water quality in the pit lake over the short to medium terms.

Further options, additional or alternative to those considered appropriate at this stage, exist and are expected to be evaluated prior to mine closure as part of this adaptive management approach. The proposed approach to water quality effects management provides options which are considered likely to be effective and therefore provide confidence to project stakeholders. During design of the water management plan further consideration and refinement of the measures proposed is expected to be undertaken.

**Comprehensive monitoring program:** Comprehensive monitoring of water quality trends is required to confirm projections for long term compliance with water quality criteria following mine closure, support the investigation of contaminant attenuation processes and enable optimisation of water quality mitigation measures. A water management plan for Macraes Phase III would involve ongoing monitoring at critical monitoring and compliance points, which will be used to confirm projected trends in water chemistry including the assumed model conservatism.

**Recommended compliance limits:** Compliance limits have been proposed for the Macraes Phase III Project which are consistent with current consents for the wider MGP. The water management plan for the Macraes Phase III Project is to include an adaptive management approach to maintain water quality at compliance points below consented compliance limits.

# 9.0 REFERENCES

Golder 2011a. Macraes Phase III Project. Top Tipperary tailings storage facility hydrogeological assessment. Report No. 0978110-562 R004 prepared for OceanaGold (New Zealand) Limited by Golder Associates (NZ) Limited, April 2011.

Golder 2011b. Macraes Phase III Project. Groundwater contaminant transport assessment – Deepdell Creek, North Branch Waikouaiti River and Murphys Creek catchments. Report No. 0978110-562 R006 prepared for OceanaGold (New Zealand) Limited by Golder Associates (NZ) Limited, April 2011.

Golder 2011c. Macraes Phase III Project. Surface water modelling report. Report 0978110-562 R008 prepared for OceanaGold (New Zealand) Limited by Golder Associates (NZ) Limited, April 2011.

Golder 2011d. Macraes Phase III. Tailings storage facility drainage rates following closure. Report No. 0978110-562 R015 prepared for OceanaGold (New Zealand) Limited by Golder Associates (NZ) Limited, April 2011.

Golder 2011e. Macraes Phase III. Golden Point pit lake seepage loss assessment. Report No. 0978110-562 R014 prepared for OceanaGold (New Zealand) Limited by Golder Associates (NZ) Limited, April 2011.

Golder 2011g. Macraes Phase III. Preliminary Options Assessment Passive Water Treatment System Top Tipperary Tailings Storage Facility. Report No. 0978110-562 R001 prepared for OceanaGold (New Zealand) Limited by Golder Associates (NZ) Limited, April 2011.

Golder 2011h. Macraes Phase III. Environmental water quality data summary report. Report No. 0978110-562 R007 prepared for OceanaGold (New Zealand) Limited by Golder Associates (NZ) Limited, April 2011.

Golder 2011i. Macraes Phase III. Tailings static and kinetic geochemical assessment. Report prepared for OceanaGold (New Zealand) Limited by Golder Associates (NZ) Limited, April 2011.

Kingett Mitchell 2005. Macraes Gold Project post closure water management. Report prepared for OceanaGold (New Zealand) Limited by Kingett Mitchell Limited, December 2005.

# APPENDIX A

## Statement of Limitations

# REPORT LIMITATIONS

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# APPENDIX B

## Deepdell Creek and Shag River Catchment Mitigation Options

# 1.0 BACK ROAD WRS UNDERDRAINS

Groundwater modelling indicates the Back Road WRS would generate a wide diffuse contaminant plume toward Deepdell Creek. The contaminant travel times from the WRS to Deepdell Creek are expected to be measured in decades, although discharges of contaminated water to the tributary gullies intersecting the WRS would begin over a much shorter time span. The large area of the proposed WRS footprint also implies a relatively large eventual contribution of additional contaminants, primarily sulphate, to Deepdell Creek. Any reduction in the projected contaminant mass load from the Back Road WRS may be significant in enabling the proposed water quality compliance limits at DC08 and existing water quality limits at Loop Road to be met.

Installation of underdrains in the gullies intersecting the proposed WRS is one potential means of capturing waste rock seepage before it enters the underlying rock mass. The underdrain discharges could be managed through treatment over the long term if necessary to meet compliance conditions. The concept of underdraining a WRS has previously been applied at the MGP. A drainage system was installed beneath the existing Northern Gully WRS. Discharge flows from the Northern Gully drains have not been monitored on a consistent basis, although visual estimates suggest they are small (D. Clarke; OceanaGold; pers. comm.).

During 2010 the discharge water from the Northern Gully WRS underdrains contained approximately 2,500 g/m$^3$ sulphate. During dry summer periods, even relatively small discharge flows at this concentration could have a significant effect on consent compliance at DC08.

Underdrainage of a WRS is however not necessarily an efficient means of reducing contaminant discharges to Deepdell Creek. It is likely that the seepage water collected by the underdrains would have discharged to silt ponds or traps downstream from the WRS in any case. The water from these silt traps could potentially be captured and managed without the necessity of installing extensive underdrains.

The main benefit underdrains provide over the capture of seepage using silt traps down-gradient from the WRS is flow rate stability. The underdrains do not present the issue of variable surface run-off to manage. This benefit could however also be achieved through the installation of small groundwater interceptor trenches that could be installed inside the toe of the proposed WRS, with a discharge drain to a water management system downstream from the WRS. The relative costs of the three options for WRS groundwater management would need to be evaluated in more detail to identify the most cost effective means of capturing WRS seepage.

Irrespective of the efficiency of leachate water capture using drainage systems, the captured water would still need management. Underdrain installation alone does not constitute a water quality mitigation measure.

# 2.0 CLOSURE STAGE MITIGATION OPTIONS

## 2.1 Deepdell Creek Base Flow Augmentation

### 2.1.1 Introduction

The construction of a fresh water dam in the Deepdell Creek catchment may be used to help mitigate non-point source water quality issues by providing greater base flow reliability. Run-off collected during periods of higher precipitation could be stored in the dam and released as a constant discharge throughout the year, thus supplementing base flows in the creek. By decreasing the frequency of critical low flows, the risk of non-compliance with consented water quality limits is reduced.

Preliminary modelling has been undertaken to assess the position, size and potential base flows achievable for dams constructed at several possible locations within the Deepdell Creek catchment. Review of the options and consenting issues that may arise has resulted in two preferred options being identified. Further modelling was undertaken to investigate the viability of these two options.

Three fresh water dam scenarios have been evaluated as potential mitigation options to achieve the minimum baseline low in Deepdell Creek to ensure the MGP meets water quality compliance concentrations for a range of contaminants in Deepdell Creek and the Shag River at their respective compliance monitoring points. The possible dam locations identified are on Camp Creek, Highlay Creek and Deepdell Creek upstream from the Maori Tommy Gully confluence (Figures 3, 4 and 5 in the main body of this report).

These mitigation scenarios are based on the assumption that a dam could be constructed that would release water at a constant rate throughout the year and thereby supplement downstream flows during natural low flow periods. These supplementary flows would provide additional dilution to contaminated water discharges from the mine site.

The primary water management issues for the use of fresh water dams for mitigation purposes are:

1) The time required to fill each of the dams.

2) The maximum constant discharge rate that could be maintained by each of the dams.

Dam filling scenarios for the proposed Camp Creek, Highlay Creek and Deepdell Creek dams were run using modified versions of the mine water management model for the MGP site (Golder 2011c).

### 2.1.2 Modelling approach

The MGP surface water model was adapted to allow for 2 separate model runs for each dam location. The initial model run utilises the 50$^{th}$ percentile artificial rainfall record for the simulation. The second model run uses a Monte Carlo set of artificial rainfall records.

The Monte Carlo model run allows for probabalistic simulations where one or more input parameters are represented as probability distributions and a simulation is carried out by running the model multiple times. In the terms of this latter model, the rainfall generator was utilised to generate a number of differing rainfall records and therefore allow for a probabilistic simulation. The Monte Carlo model was set to run 200 realisations (or 200 independently generated rainfall datasets). The results (200 sets of 30 year time series outcomes of dam filling records) were analysed and resulted in a probabilistic dam filling dataset for the Camp Creek and Highlay Creek dams. The rainfall generator and probabilistic generator are documented in greater detail in the site wide modelling report (Golder 2011c).

The inital model run for each dam site was run for the closure stage only (1/1/2019 – 1/1/2169) using the 50$^{th}$ percentile rainfall dataset. This model was used to optimise the release rate the dam could sustain without becoming dry. A Monte Carlo type model run was used to determine the time to fill each dam to capacity. For the purpose of the modelling the timing of the simulation is arbitrary. As such, it has been assumed that the dams are constructed prior to January 2011 and allowed to fill at the start of January 2011.

### 2.1.3 Key assumptions

Critical assumptions in the modelling of dam filling times and continuous discharge rates Include:

- During the dam construction period and for the time required for the dam to reach an overflow, there is no managed discharge.
- Seepage losses through the dams are negligible.
- The surface water run-off characteristics of the catchments upstream from the proposed dams are similar to those for Deepdell Creek as measured at the Golden Point Weir monitoring station. This implies that the discharge flows from the Camp Creek and Highlay Creek catchments resulting from specified rainfall events are directly proportional to the flows that would occur at Golden Point Weir following the same rainfall events.

The locations and potential heights of the dams are as presented in Table B1.

**Table B1: Critical layout assumptions for fresh water dam modelling.**

| Assumption | Camp Creek Dam | Highlay Creek Dam | Deepdell Creek Dam |
|---|---|---|---|
| Catchment area upstream of the dam (km$^{2}$) | 10.9 | 5.9 | 20 |
| Maximum dam height (m) | 40 | 30 | 32.5 |

### 2.1.4 Projected Water Quality Limitations

The water quality outcomes of modelled mitigation options are reported as the 99$^{th}$ percentile concentration rather than the maximum projected concentration as indicated in Golder 2011a. Use of a 99$^{th}$ percentile for assessing the likely achievement of compliance is considered appropriate rather than the maximum projected concentrations as discussed in Section 2.8 of the main body of this report. The 99th percentile is considered an "effectively mitigated" outcome for the simulations, taking into account model and sampling limitations and is reported using this term.

The proposed Camp Creek fresh water dam is located north-west of the Macraes mine site (refer main report, Figure 3). The dam reservoir covers a maximum area of approximately 164,000 m$^2$ and fills to a maximum volume of approximately 2 Mm$^3$ before overtopping. The maximum design height of the dam face is approximately 45 m above the stream bed. The dam bathymetry has been calculated using GIS and dam volume, dam surface area and dam height relationships have been calculated (Table B2).

**Table B2: Camp Creek dam height to volume and surface area relationship.**

| Dam height (m)$^{(1)}$ | Volume (m$^3$) | Area (m$^2$) |
|---|---|---|
| 0 | 0 | 0 |
| 5 | 1,300 | 1,300 |
| 10 | 25,000 | 7,900 |
| 15 | 75,000 | 12,000 |
| 20 | 149,000 | 21,000 |
| 25 | 293,000 | 36,000 |
| 30 | 502,000 | 48,000 |
| 35 | 777,000 | 64,000 |
| 40 | 1,239,000 | 140,000 |
| 45 | 2,039,000 | 164,000 |

**Note:** 1) Relative to the base of the dam.

Modelling indicates construction and operation of a dam on Camp Creek to the maximum proposed size could provide a continuous release of approximately 7 L/s to supplement the low flows in Deepdell Creek. Camp Creek is considered to be ephemeral, with modelled inflows to the dam varying between nothing and approximately 6,000 L/s with an average inflow of around 21 L/s. Taking into account a continuous release of 7 L/s, the modelled dam volume varied between 400,000 m$^3$ and approximately 2 Mm$^3$ with an average volume of around 1.7 Mm$^3$. The dam could be expected to overflow approximately 10% of the time (Figure B1). Modelling indicates a continuous release rate of 7 L/s corresponds would effectively maintain a minimum baseflow of 32 L/s in Deepdell Creek at DC08 assuming all contributing flows (groundwater seepage, etc.) are similar to model assumptions.

The constant release rate discussed above does not vary seasonally or in response to changes in flows in Deepdell Creek or the Shag River. A managed release rate from the dam, with discharges only during periods of low flow downstream, could provide a substantially larger augmentation flow (estimated 15 L/s) for shorter periods.

A Monte Carlo modelling approach was used to evaluate the Camp Creek dam filling times. Based on the mean filling times calculated in the model, the Camp Creek dam could be expected to take approximately 6 years to fill to 2 $Mm^3$ or to the overflow at the 45 m dam height. Based on a particularly wet scenario, represented by the 95$^{th}$ percentile filling rate, the dam could take approximately 2 years to fill. Based on a particularly dry scenario, represented by the 5$^{th}$ percentile filling rate, the dam could take approximately 8 years to fill (Figure B2).

No residual discharge was taken into account in this assessment of filling times. A small discharge released for ecological protection purposes during filling periods for the dam should not substantially affect the filling times.

The mine water management model is considered to be more conservative with respect to water quality projections for the Shag River than for Deepdell Creek. This expectation is supported by observed water quality at DC07 and Loop Road during November 2006. At that time inadvertent releases of mine water resulted in sulphate concentrations in Deepdell Creek exceeding 1,000 $g/m^3$. At about the same time the observed sulphate concentration in the Shag River at Loop Road was less than 160 $g/m^3$. Since that time the observed sulphate concentrations at Loop Road have not exceeded 50 $g/m^3$, whereas the concentrations at DC07 have reached or exceeded 500 $g/m^3$ twice. These ratios indicate that if compliance with the sulphate criterion at DC07 or DC08 can be achieved, then it is likely that compliance would also be achieved for sulphate at Loop Road.

The surface water model incorporating the Camp Creek dam indicated sulphate would effectively mitigated in Deepdell Creek during operational and closure stages. This level of compliance applied to all of the contaminants for which compliance limits on these waterways have been defined, including both arsenic (Table B3) and sulphate (Table B4). Although the surface water model projections for arsenic concentrations in the Shag River exceed the compliance limit attenuation has not been modelled and therefore this exceedance is not likely to be observed.

**Table B3: Projected 99$^{th}$ percentile concentrations for arsenic (unattenuated) with Camp Creek dam.**

| Model Run | Dam Flow Rates | DC08 | Shag @ Loop |
|---|---|---|---|
| Unmitigated | N/A | 0.20 | 0.044 |
| Camp Creek Dam | Release rate: 7 L/s | 0.14 | 0.04 |

**Notes:** All units $g/m^3$ unless otherwise stated.

**Table B4: Projected 99$^{th}$ percentile concentrations for sulphate with Camp Creek dam.**

| Model Run | Dam Flow Rates | DC08 | Shag @ Loop |
|---|---|---|---|
| Unmitigated | N/A | 1,150 | 290 |
| Camp Creek Dam | Release rate: 7 L/s | 810 | 270 |
| Camp Creek Dam, staged release | Release rate: 15 L/s | | 246 |

**Notes**: All units $g/m^3$ unless otherwise stated.

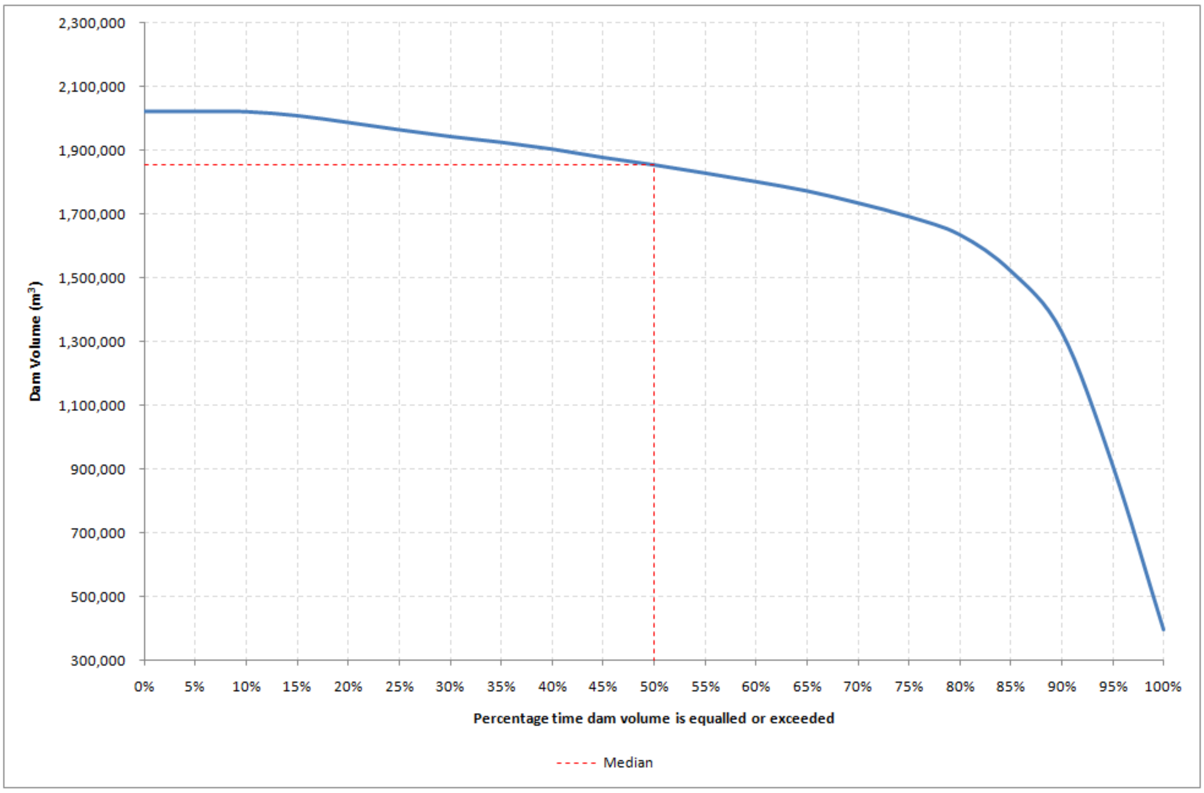


*Figure B1: Camp Creek Dam volume as a function of time.*

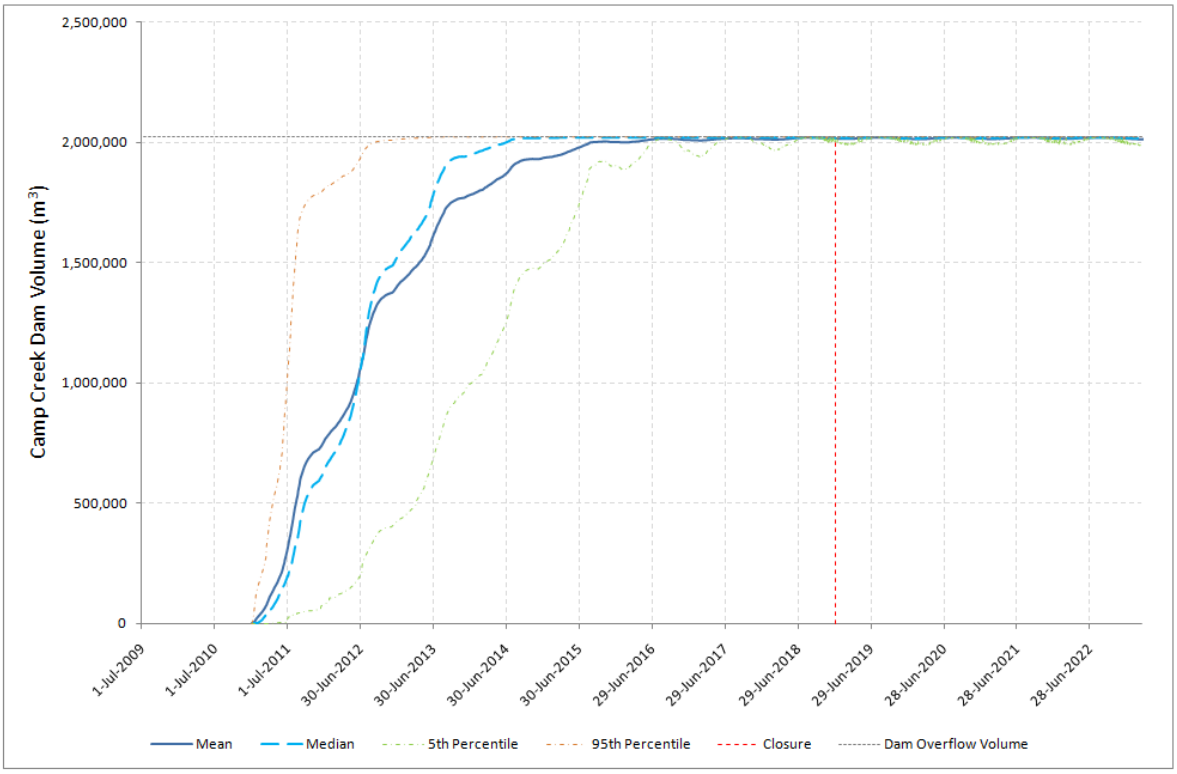


*Figure B2: Camp Creek dam filling rates.*

### 2.1.5 Highlay Creek fresh water dam

The proposed Highlay Creek fresh water dam is located north-east of the Macraes mine site (refer main report, Figure 4). The dam reservoir covers a maximum area of approximately 162,000 $m^2$ and fills to a maximum volume of 1.7 $Mm^3$ before overtopping. The design height of the dam face is approximately 40 m above the stream bed. The dam bathymetry has been calculated using GIS and dam volume, dam surface area and dam height relationships have been calculated (Table B5).

**Table B5: Highlay Creek volume, area dam height relationship.**

| Dam height (m)[1] | Volume ($m^3$) | Area ($m^2$) |
|---|---|---|
| 0 | 0 | 0 |
| 5 | 190 | 1,400 |
| 10 | 22,000 | 7,200 |
| 15 | 73,000 | 17,000 |
| 20 | 193,000 | 30,000 |
| 25 | 369,000 | 45,000 |
| 30 | 655,000 | 69,000 |
| 35 | 1,063,000 | 106,000 |
| 40 | 1,734,000 | 162,000 |

**Note:** 1) Relative to the base of the dam.

Modelling indicates construction and operation of a dam on Highlay Creek to the maximum proposed size could provide a continuous release of approximately 4 L/s to supplement the low flows in Deepdell Creek. Highlay Creek is considered to be ephemeral, with modelled inflows to the dam varying between nothing and approximately 3,200 L/s with an average inflow of around 16 L/s.

The constant release rate discussed above does not vary seasonally or in response to changes in flows in Deepdell Creek or the Shag River. A managed release rate from the dam, with discharges only during periods of low flow downstream, could provide a substantially larger augmentation flow for shorter periods.

A Monte Carlo modelling approach was used to evaluate the Highlay Creek dam filling times. Based on the mean filling times calculated in the model, the Highlay Creek dam could be expected to take approximately 9 to 10 years to fill to 1.7 $Mm^3$ or to the overflow at the 40 m dam height. Based on a particularly wet scenario, represented by the 95$^{th}$ percentile filling rate, the dam could take approximately 3 to 4 years to fill. Based on a particularly dry scenario, represented by the 5$^{th}$ percentile filling rate, the dam could take in excess of 12 years to fill (Figure B3).

No residual discharge was taken into account in this assessment of filling times. A small discharge released for ecological protection purposes during filling periods for the dam should not substantially affect the filling times.

The surface water model incorporating the Highlay Creek dam indicated compliance with sulphate limits for Deepdell Creek and the Shag River could not be achieved using this dam as the sole source of dilution water. This is a consequence of the relatively small catchment area and associated small potential constant rate of water discharge.

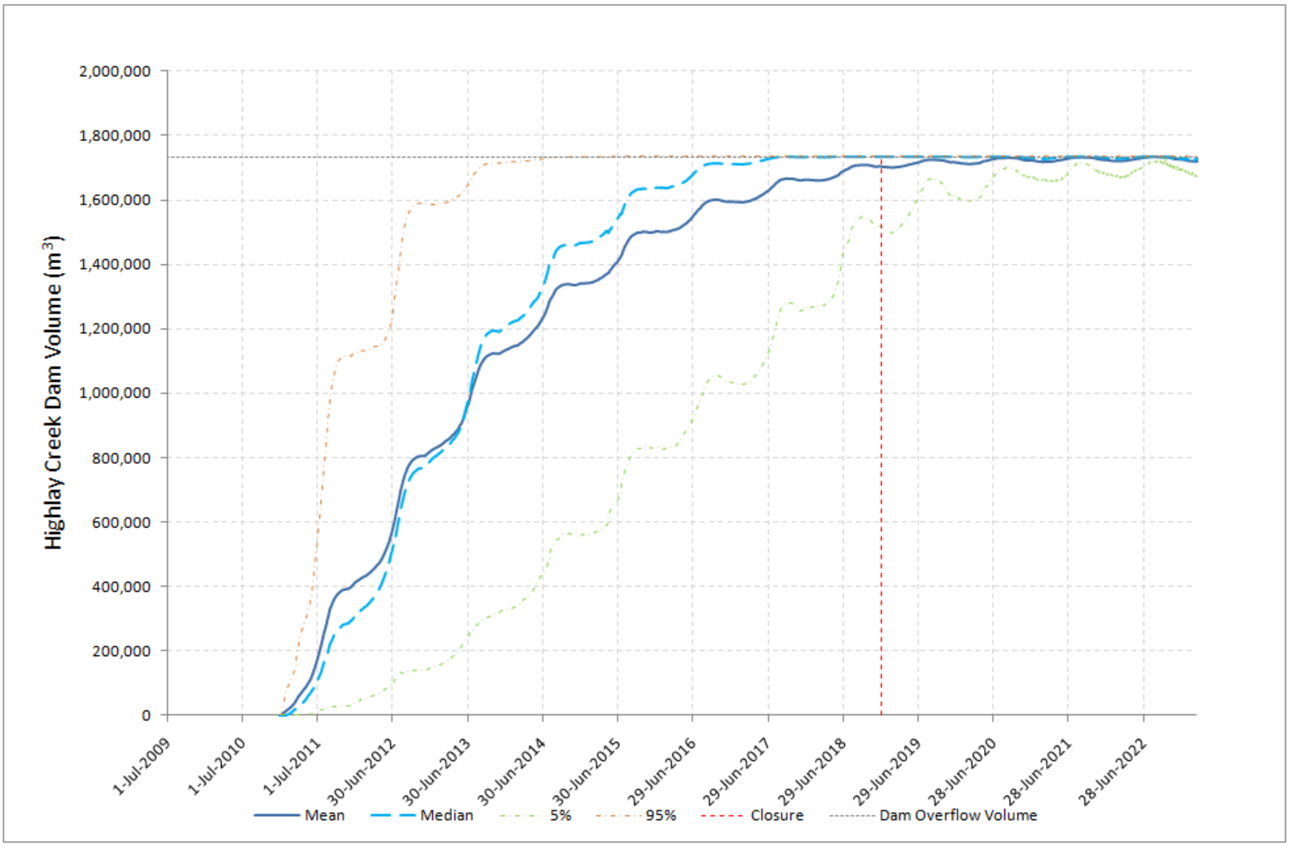


*Figure B3: Highlay Creek dam filling rates.*

## 2.1.6 Deepdell Creek freshwater dam

The Deepdell Creek dam scenario incorporates a large fresh water dam immediately upstream of the Maori Tommy Gully confluence (main report Figure 5). The Deepdell Creek reservoir would cover a maximum area of approximately 200,000 m$^2$ and fill to a maximum volume of 1.9 Mm$^3$ before overtopping. The design height of the dam face would be approximately 32.5 m above the stream bed. The dam bathymetry has been calculated using GIS and dam volume, dam surface area and dam height relationships have been calculated (Table B6).

Modelling indicates construction and operation of a dam on Deepdell Creek to the maximum proposed size could provide a continuous release of approximately 26 L/s to supplement the low flows in Deepdell Creek. Deepdell Creek is ephemeral, with modelled inflows to the dam varying between nothing and approximately 23,500 L/s with an average inflow of around 71 L/s. Taking into account a continuous release of 26 L/s, the modelled dam volume varied between 800,000 m$^3$ and approximately 1.9 Mm$^3$ with an average volume of around 1.7 Mm$^3$.

The dam filling time is estimated to be around 7 months based on modelled projections. No residual discharge was taken into account in this assessment of filling times. A small discharge released for ecological protection purposes during filling periods for the dam should not substantially affect the filling times. Figure B4 presents the percentage of time a particular volume in the dam is equalled or exceeded.

The constant release rate discussed above does not vary seasonally or in response to changes in flows in Deepdell Creek or the Shag River. A managed release rate from the dam, with discharges only during periods of low flow downstream, could provide a substantially larger augmentation flow for shorter periods.

**Table B6: Deepdell Creek volume, area dam height relationship.**

| Dam height (m)[1] | Volume ($m^3$) | Area ($m^2$) |
|---|---|---|
| 0 | 1,800 | 2,600 |
| 2.5 | 12,000 | 5,400 |
| 5 | 31,000 | 10,000 |
| 7.5 | 71,000 | 25,000 |
| 10 | 144,000 | 32,000 |
| 12.5 | 232,000 | 38,000 |
| 15 | 336,000 | 45,000 |
| 17.5 | 455,000 | 51,000 |
| 22.5 | 741,000 | 64,000 |
| 25 | 907,000 | 70,000 |
| 27.5 | 1,100,000 | 88,000 |
| 30 | 1,400,000 | 170,000 |
| 32.5 | 1,880,000 | 200,000 |

**Note:** 1) Relative to the base of the dam.

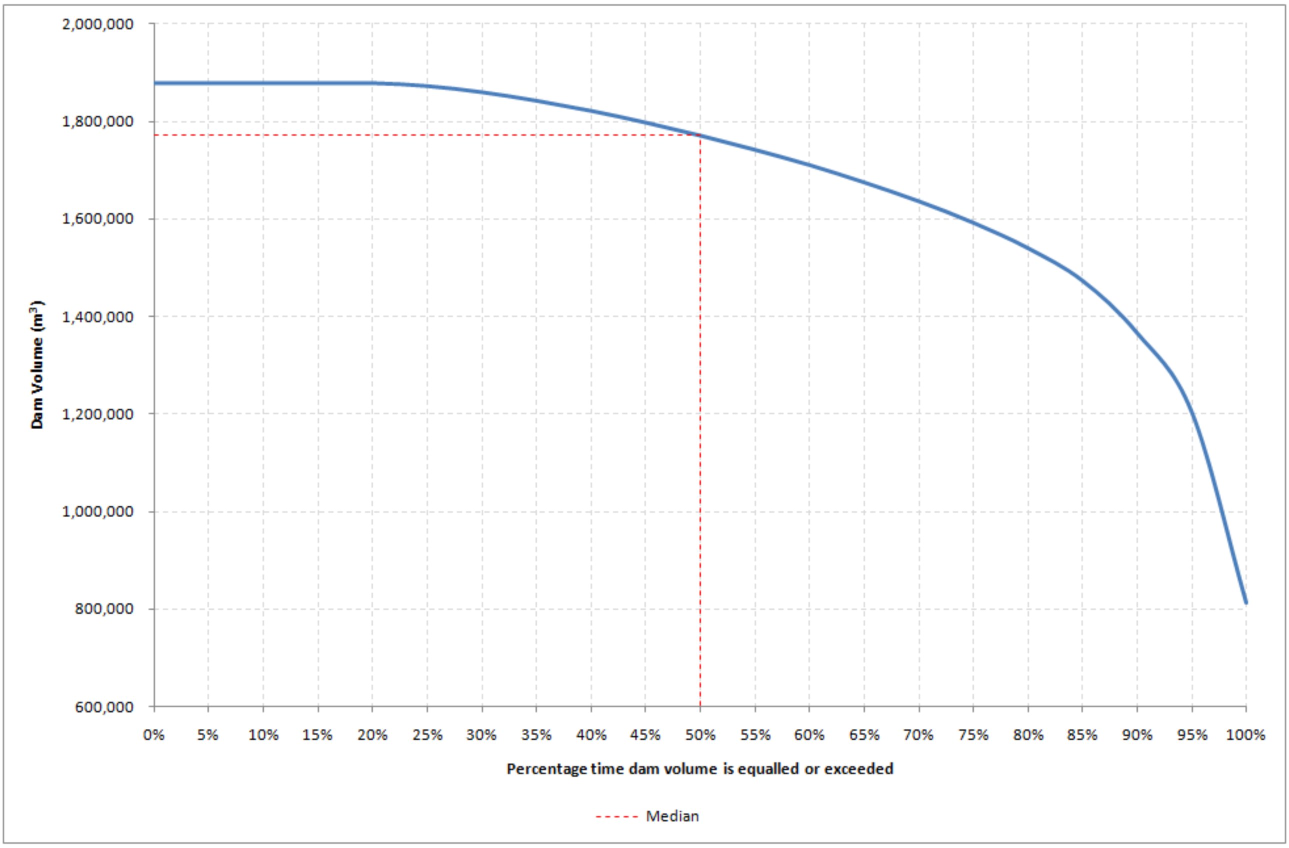


*Figure B4: Deepdell Creek Dam volume as a function of time.*

Modelling indicates the constant release rate of approximately 26 L/s from Deepdell Creek dam (which corresponds to a minimum baseflow of approximately 50 L/s in Deepdell Creek at DC08) would be sufficient to mitigate arsenic and sulphate concentrations at DC08 and sulphate concentrations in the Shag River. If it is assumed that arsenic is conservatively transported, this discharge rate may not be sufficient to mitigate for arsenic in the Shag River at Loop Road. The modelled geochemical outputs for arsenic and sulphate are summarised in Table B7 and Table B8.

**Table B7: Projected 99th percentile concentrations for arsenic (unattenuated) with Deepdell Creek freshwater dam.**

| Model Run (1) | Dam Flow Rates | DC08 | Shag @ Loop |
|---|---|---|---|
| Unmitigated | N/A | 0.20 | 0.044 |
| Deepdell Creek Dam | Release rate: 26 L/s | 0.09 | 0.03 |

**Note:** 1) All units g/m$^3$ unless otherwise stated.

**Table B8: Projected 99th percentile concentrations for sulphate with Deepdell Creek freshwater dam.**

| Model Run (1) | Dam Flow Rates | DC08 | Shag @ Loop |
|---|---|---|---|
| Unmitigated | N/A | 1,150 | 290 |
| Deepdell Creek Dam | Release rate: 26 L/s | 520 | 210 |

**Note:** 1) All units g/m$^3$ unless otherwise stated.

### 2.1.7 Lone Pine Reservoir

The Lone Pine water storage reservoir (Lone Pine) is located in the Maori Tommy Gully catchment to the northwest of the process plant. Lone Pine currently acts as the water reservoir for the process plant; however it has the potential to act as a long-term storage dam discharging to Deepdell Creek. If used as such, Lone Pine could contribute to the maintenance of a baseflow in Deepdell Creek in order to reduce the risk of non-compliance with consented water quality limits.

The concept is based on a modification of the mine run-off drainage system following closure to ensure that Lone Pine receives the run-off from the MTI. Simulations indicate Lone Pine by itself does not have sufficient catchment area or storage capacity to prevent critical low flows in Deepdell Creek. Inflows to the reservoir following closure are ephemeral and have median and mean flows of less than 1 L/s and approximately 4 L/s, respectively. Modelling suggests that Lone Pine would occasionally be empty if a constant flow was to be released to augment base flows in Deepdell Creek. For this reason Lone Pine is not considered suitable for this purpose. Lone Pine could however play a role in supporting other mitigation measures implemented in the catchment.

## 2.2 Passive Water Treatment Systems

A passive treatment system can be instigated to treat the combined drain and seepage water from the MTI/SPI requiring mitigation. Passive treatment, as described in Section 4.2.2 of the main report, is a viable option for reducing concentrations in mine influenced water. Reductions of TSF drain and groundwater seepage discharge concentrations for arsenic and sulphate by 90% has been shown through surface water modelling to be likely to achieve existing and proposed compliance criteria on Deepdell Creek and the Shag River.

Sulphate from WRS's contribute significantly to the total sulphate concentrations measured at the DC08 and Shag compliance points. A summary of the modelled geochemical outcomes for arsenic and sulphate are summarised on Table B9 and Table B10.

**Table B9: Projected 99th percentile concentrations for arsenic with passive treatment (post closure).**

| Model Run (1) | DC08 | Shag @ Loop |
|---|---|---|
| Unmitigated | 0.20 | 0.044 |
| 75% Mitigation TSF Drains and GW seepage | 0.07 | 0.02 |
| 90% Mitigation TSF Drains and GW seepage | 0.05 | 0.01 |

**Note:** 1) All units g/m$^3$ unless otherwise stated.

**Table B10: Projected 99th percentile concentrations for sulphate with passive treatment (post closure).**

| Model Run (1) | DC08 | Shag @ Loop |
|---|---|---|
| Unmitigated | 1,150 | 290 |
| 75% Mitigation TSF Drains and GW seepage | 780 | 210 |
| 90% Mitigation TSF Drains and GW seepage | 750 | 190 |

**Note:** 1) All units g/m$^3$ unless otherwise stated.

Three components of a passive water treatment system to remove arsenic, sulphate and iron from mine water are described in Section 4.2.2 of the mine report. The installation of the aerobic cell described could be expected to substantially reduce iron and arsenic concentrations together with other metals that may also become oxidised and combine with the iron. Since the individual components of the passive treatment system outlined in the main report are targeted to treat particular contaminant suites, the components can be separated for use in combinations with other mitigation options. For example, treatment for arsenic through an iron-arsenic aerobic cell can be combined with a freshwater dam for mitigation of sulphate. Installation of an aerobic cell to remove iron from TSF drain discharges would reduce the possible development of iron flocculants and staining in Maori Tommy Gully and Deepdell Creek.

## 2.3 Low Permeability TSF Cap

Current rehabilitation planning for the TSF's incorporates the placement of a soil and waste rock cover on top of the tailings. One of the objectives is to reduce rainwater infiltration to the equivalent of the regional recharge rate through retention of the moisture in the soils. It is considered that this objective is being achieved.

It is unlikely that a lower recharge rate to stored tailings could be achieved through simply applying a low permeability cap using materials available at the site. This conclusion is partly based on the probable lack of sufficient low permeability capping material at the site.

Constructing an impermeable cap using clay, geotextiles or other forms of artificial covering material could potentially reduce the rate of infiltration. A modified groundwater model was developed for the TTTSF which simulated the infiltration rate through the tailings surface to zero. The result showed seepage losses were reduced. At the end of the 150 year simulation period however the simulated seepage rate was still declining. At that stage the drain flows were approximately 60% of the simulated drain flows from the uncapped TSF.

Although the groundwater model is likely to substantially understate the rate at which the drain flows decrease following closure, it is unlikely that the initial rate of decrease would be accelerated significantly due to an impermeable cap being installed. Over the long term capping of the TSF could negate the need to apply other permanent mitigation measures to the catchment. The time required before the point at which no further mitigation would be required is however uncertain and it is probable some form of mitigation would be needed during the intervening period. It is doubtful that the drain flows, even with capping, would ever decline to zero.

Capping the MTI and SPI in this manner would be an expensive project, and would not be a complete solution. Ongoing issues that would still arise with capping include:

- Ongoing monitoring and maintenance - this option does not provide a permanent solution to the potential contamination of the surrounding catchment unless regular monitoring and maintenance of capping materials is implemented.
- Potential dying off of re-vegetation - the wetting and drying cycle in the soils overlying the cap would be more extreme than in those across the remainder of the site. Major rainfall events could lead to soil saturation while the summers would probably be characterised by extended periods of parched soils. The limited rooting depth would limit vegetation capacity to access moisture in deeper soils.
- Erosion -run-off erosion can lead to exposure of the impermeable layer, with the attendant risk of damage.
- Limits on use - potential post-closure land use options of the capped surface are limited by the above issues.

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# APPENDIX C

## Downstream surface water availability

**Table 1: Calculated surface water flow statistics for current conditions.**

| Site | Catchment area ($km^2$) | Records used for flows statistics (1) | Mean | Median | 98th percentile | 90th percentile | 80th percentile | MAM (2) (1 day) | MAM (2) (7 Day) |
|---|---|---|---|---|---|---|---|---|---|
| DC07 | 51.6 | 1985-2010 pre-mining and existing | 121.4 | 37.9 | 0.7 | 4.4 | 9.5 | 3.7 | 5.0 |
| DC08 | 56.8 | 1985-2010 pre-mining and existing | 133.6 | 41.8 | 0.8 | 4.9 | 10.4 | 4.1 | 5.5 |
| TC01 | 6.0 | 1985-2010 pre-mining and existing | 14.1 | 4.4 | 0.1 | 0.5 | 1.1 | 0.4 | 0.6 |
| CJ01 | 5.1 | 1985-2010 pre-mining and existing | 12.0 | 3.8 | 0.1 | 0.4 | 0.9 | 0.4 | 0.5 |
| Loop Road | 263.3 | 1989-2010 pre-mining and existing | 1,314 | 465 | 54 | 125 | 192 | 133 | 149 |
| McCormicks | 345.3 | 1989-2010 pre-mining and existing | 1,723 | 609 | 70 | 164 | 252 | 174 | 196 |
| NBWRRB | 3.4 | 1976-1987 pre mining | 21.3 | 6.7 | 0.4 | 1.0 | 2.0 | 0.8 | 1.0 |
| NBWRRF | 27.0 | 1976-1987 pre mining | 169.4 | 53.5 | 3.3 | 8.3 | 15.7 | 6.1 | 8.2 |
| MC100 | 2.6 | 1976-1987 pre mining | 16.3 | 5.2 | 0.3 | 0.8 | 1.5 | 0.6 | 0.8 |
| MC01 | 4.9 | 1976-1987 pre mining | 30.7 | 9.7 | 0.6 | 1.5 | 2.9 | 1.1 | 1.5 |
| NB03 | 44.9 | 1976-1987 pre mining | 282 | 89 | 5.4 | 13.8 | 26.2 | 10.2 | 13.6 |

**Note:** 1) All values in L/s unless otherwise stated.
2) MAM = Mean Annual Minimum flow

**Table 2: During Macraes Phase III operations with no water quality mitigation measures applied.**

| Site | Catchment area change relative to current | | Mean | Median | 98th | 90th | 80th | MAM (1) (1 day) | MAM (1) (7 Day) |
|---|---|---|---|---|---|---|---|---|---|
| | $km^2$ | Comment | L/s | L/s | L/s | L/s | L/s | L/s | L/s |
| DC07 | -2.3 | Loss of catchments for Lone Pine, MTG and SPI already occurring and partly included in flow statistics. Maximum possible change included for Macraes Phase III to be conservative. | 116.0 | 36.2 | 0.7 | 4.2 | 9.1 | 3.5 | 4.8 |
| DC08 | -2.3 | As for DC07 | 128.2 | 40.1 | 0.8 | 4.7 | 10.0 | 3.9 | 5.3 |
| TC01 | -2.5 | Decrease due to Top Tipperary TSF. | 8.2 | 2.6 | 0.1 | 0.3 | 0.6 | 0.2 | 0.4 |
| CJ01 | 0.0 | No change. | 12.0 | 3.8 | 0.1 | 0.4 | 0.9 | 0.4 | 0.5 |
| Loop Road | -2.3 | As for DC07 | 1302.5 | 460.9 | 53.5 | 123.9 | 190.3 | 131.8 | 147.7 |
| McCormicks | -4.8 | Combined from DC07 and TC01. | 1699.0 | 600.5 | 69.0 | 161.7 | 248.5 | 171.6 | 193.3 |
| NBWRRB | 0.5 | Frasers waste rock stack increases catchment area | 24.2 | 7.6 | 0.5 | 1.1 | 2.3 | 0.9 | 1.1 |
| NBWRRF | 0.5 | As for NBWRRB | 172.3 | 54.4 | 3.4 | 8.4 | 16.0 | 6.2 | 8.3 |
| MC100 | 0.0 | Frasers West WRS in catchment alters flow paths but does not change catchment area | 16.3 | 5.2 | 0.3 | 0.8 | 1.5 | 0.6 | 0.8 |
| MC01 | 0.0 | As for MC100 | 30.7 | 9.7 | 0.6 | 1.5 | 2.9 | 1.1 | 1.5 |
| NB03 | 0.5 | As for NBWRRB | 284.7 | 89.9 | 5.5 | 13.9 | 26.4 | 10.3 | 13.7 |

**Note:** 1) MAM = Mean Annual Minimum flow

**Table 3: During Macraes Phase III operations, incorporating Camp Creek Dam filling with no residual discharge.**

| Site | Catchment area change relative to current | | Mean | Median | 98th | 90th | 80th | MAM (1) (1 day) | MAM (1) (7 Day) |
|---|---|---|---|---|---|---|---|---|---|
| | km² | Comment | L/s | L/s | L/s | L/s | L/s | L/s | L/s |
| DC07 (2) | -13.2 | Loss of catchments for Lone Pine, MTG and SPI already occurring and partly included in flow statistics. Maximum possible change included for Macraes Phase III to be conservative. | 90.4 | 28.2 | 0.5 | 3.3 | 7.1 | 2.8 | 3.7 |
| DC08 | -13.2 | As with DC07 | 102.6 | 32.1 | 0.6 | 3.8 | 8.0 | 3.1 | 4.2 |
| TC01 | -2.5 | Decrease due to Top Tipperary TSF | 8.2 | 2.6 | 0.1 | 0.3 | 0.6 | 0.2 | 0.4 |
| CJ01 | 0.0 | No change | 12.0 | 3.8 | 0.1 | 0.4 | 0.9 | 0.4 | 0.5 |
| Loop Road | -13.2 | As with DC07 | 1248.2 | 441.7 | 51.3 | 118.7 | 182.4 | 126.3 | 141.5 |
| McCormicks | -15.7 | As outlined above | 1644.7 | 581.3 | 66.8 | 156.5 | 240.5 | 166.1 | 187.1 |
| NBWRRB | 0.5 | Frasers waste rock stack increases catchment area | 24.2 | 7.6 | 0.5 | 1.1 | 2.3 | 0.9 | 1.1 |
| NBWRRF | 0.5 | As with NBWRRB | 172.3 | 54.4 | 3.4 | 8.4 | 16.0 | 6.2 | 8.3 |
| MC100 | 0.0 | Frasers West WRS in catchment alters flow paths but does not change catchment area | 16.3 | 5.2 | 0.3 | 0.8 | 1.5 | 0.6 | 0.8 |
| MC01 | 0.0 | As with MC100 | 30.7 | 9.7 | 0.6 | 1.5 | 2.9 | 1.1 | 1.5 |
| NB03 | 0.5 | As with NBWRRB | 284.7 | 89.9 | 5.5 | 13.9 | 26.4 | 10.3 | 13.7 |

**Note:** 1) MAM = Mean Annual Minimum flow

2) A small residual discharge from Camp Creek Dam could be released during the construction and filling period for ecological purposes if necessary. The values presented in this table represent a lowest flow scenario for Deepdell Creek with no residual discharge from Camp Creek Dam.

**Table 4: Following MGP closure and site rehabilitation with TSF discharges pumped to Frasers Pit and no other mitigation.**

| Site | Catchment area change relative to current | | Mean | Median | 98th | 90th | 80th | MAM (1) (1 day) | MAM (1) (7 Day) |
|---|---|---|---|---|---|---|---|---|---|
| | km$^2$ | Comment | L/s | L/s | L/s | L/s | L/s | L/s | L/s |
| DC07 | nil | Lone Pine catchment, MTI and MTG will be rehabilitated have assumed flows will return to pre-mining situation and that initial flow stats are predominantly pre mine | 121.4 | 37.9 | 0.7 | 4.4 | 9.5 | 3.7 | 5.0 |
| DC08 | nil | as above | 133.6 | 41.8 | 0.8 | 4.9 | 10.4 | 4.1 | 5.5 |
| TC01 | nil | Top Tipperary TSF rehabilitated | 14.1 | 4.4 | 0.1 | 0.5 | 1.1 | 0.4 | 0.6 |
| CJ01 | nil | no change | 12.0 | 3.8 | 0.1 | 0.4 | 0.9 | 0.4 | 0.5 |
| Loop Road | nil | as above | 1314.0 | 465.0 | 54.0 | 125.0 | 192.0 | 133.0 | 149.0 |
| McCormicks | nil | as above | 1723.0 | 609.0 | 70.0 | 164.0 | 252.0 | 174.0 | 196.0 |
| NBWRRB | 0.5 | Frasers waste rock stack increases catchment area | 24.2 | 7.6 | 0.5 | 1.1 | 2.3 | 0.9 | 1.1 |
| NBWRRF | 0.5 | as above | 172.3 | 54.4 | 3.4 | 8.4 | 16.0 | 6.2 | 8.3 |
| MC100 | nil | Frasers West WRS in catchment alters flow paths but does not change catchment area | 16.3 | 5.2 | 0.3 | 0.8 | 1.5 | 0.6 | 0.8 |
| MC01 | nil | as above | 30.7 | 9.7 | 0.6 | 1.5 | 2.9 | 1.1 | 1.5 |
| NB03 | 0.5 | as above | 284.7 | 89.9 | 5.5 | 13.9 | 26.4 | 10.3 | 13.7 |

**Table 5: Following MGP closure and site rehabilitation with TSF discharges pumped to Frasers Pit and no discharges from Camp Creek Dam.**

| Site | Catchment area change relative to current | | Mean | Median | 98th | 90th | 80th | MAM (1) (1 day) | MAM (1) (7 Day) |
|---|---|---|---|---|---|---|---|---|---|
| | $km^2$ | Comment | L/s | L/s | L/s | L/s | L/s | L/s | L/s |
| DC07 | -10.9 | Assume catchment of Camp Creek dam removed, is worst case lowering of flows as water will actually be returned but unclear where and when | 95.8 | 29.9 | 0.6 | 3.5 | 7.5 | 2.9 | 3.9 |
| DC08 | -10.9 | as above | 108.0 | 33.8 | 0.6 | 4.0 | 8.4 | 3.3 | 4.4 |
| TC01 | nil | no change | 8.2 | 2.6 | 0.1 | 0.3 | 0.6 | 0.2 | 0.4 |
| CJ01 | nil | no change | 12.0 | 3.8 | 0.1 | 0.4 | 0.9 | 0.4 | 0.5 |
| Loop Road | -10.9 | as above | 1259.6 | 445.8 | 51.8 | 119.8 | 184.1 | 127.5 | 142.8 |
| McCormicks | -10.9 | as above | 1668.6 | 589.8 | 67.8 | 158.8 | 244.0 | 168.5 | 189.8 |
| NBWRRB | 0.5 | Frasers waste rock stack increases catchment area | 24.2 | 7.6 | 0.5 | 1.1 | 2.3 | 0.9 | 1.1 |
| NBWRRF | 0.5 | as above | 172.3 | 54.4 | 3.4 | 8.4 | 16.0 | 6.2 | 8.3 |
| MC100 | nil | Frasers West WRS in catchment alters flow paths but does not change catchment area | 16.3 | 5.2 | 0.3 | 0.8 | 1.5 | 0.6 | 0.8 |
| MC01 | nil | as above | 30.7 | 9.7 | 0.6 | 1.5 | 2.9 | 1.1 | 1.5 |
| NB03 | 0.5 | as above | 284.7 | 89.9 | 5.5 | 13.9 | 26.4 | 10.3 | 13.7 |

**Table 6: Following MGP closure and site rehabilitation with TSF discharges pumped to Frasers Pit and 10 L/s discharge from Camp Creek Dam.**

| Site | Catchment area change relative to current | | Mean | Median | 98th | 90th | 80th | MAM (1) (1 day) | MAM (1) (7 Day) |
|---|---|---|---|---|---|---|---|---|---|
| | $km^2$ | Comment | L/s | L/s | L/s | L/s | L/s | L/s | L/s |
| DC07 | -10.9 | Assume catchment of Camp Creek dam removed, is worst case lowering of flows as water will actually be returned but unclear where and when all 10L/s residual flow | 105.8 | 39.9 | 10.6 | 13.5 | 17.5 | 12.9 | 13.9 |
| DC08 | -10.9 | as above | 118.0 | 43.8 | 10.6 | 14.0 | 18.4 | 13.3 | 14.4 |
| TC01 | nil | no change | 8.2 | 2.6 | 0.1 | 0.3 | 0.6 | 0.2 | 0.4 |
| CJ01 | nil | no change | 12.0 | 3.8 | 0.1 | 0.4 | 0.9 | 0.4 | 0.5 |
| Loop Road | -10.9 | as above | 1269.6 | 455.8 | 61.8 | 129.8 | 194.1 | 137.5 | 152.8 |
| McCormicks | -10.9 | as above | 1678.6 | 599.8 | 77.8 | 168.8 | 254.0 | 178.5 | 199.8 |
| NBWRRB | 0.5 | Frasers waste rock stack increases catchment area | 27.6 | 8.7 | 0.5 | 1.3 | 2.6 | 1.0 | 1.3 |
| NBWRRF | 0.5 | as above | 175.3 | 55.4 | 3.4 | 8.6 | 16.3 | 6.3 | 8.5 |
| MC100 | nil | Frasers West WRS in catchment alters flow paths but does not change catchment area | 16.3 | 5.2 | 0.3 | 0.8 | 1.5 | 0.6 | 0.8 |
| MC01 | nil | as above | 30.7 | 9.7 | 0.6 | 1.5 | 2.9 | 1.1 | 1.5 |
| NB03 | 0.5 | as above | 287.7 | 90.8 | 5.5 | 14.1 | 26.7 | 10.4 | 13.9 |

# APPENDIX D
## Tipperary Creek Catchment Mitigation Options

# 1.0 CLOSURE STAGE MITIGATION OPTIONS

## 1.1 Pump TSF Decant and Drain Water to Frasers Pit for 20 Years

Following closure of the MGP site, rehabilitation planning required that remaining water in TSF decant ponds is pumped down and disposed of (Kingett Mitchell 2005). During the initial post-closure period it was expected that discharges from the TTTSF drain systems would be large and the water quality too poor to be directly released to Tipperary Creek or to be treated and released. The current post-closure MGP site management plan incorporates pumping of TSF decant and drain discharge water to Frasers Pit for an initial period of up to 10 years following closure of the TSF. The decant pond would be removed within a relatively short period. It is however uncertain exactly how long discharges would need to be pumped to Frasers Pit before other mitigation options could be instigated to ensure the discharges could be released to Tipperary Creek while complying with proposed water quality consent limits.

Modelling of the MGP water management system for the purposes of Macraes Phase III Project has incorporated a base case assumption that decant water from the TTTSF and all TSF drainage discharges are pumped to Frasers Pit for a period of up to 20 years following closure of the MGP. Modelling of pit filling and evaporation rates indicate Frasers Pit is very unlikely to overflow within a 150 year period following closure of the site. The pumping of the TTTSF decant pond and TSF drain discharges to Frasers Pit does not change this outcome.

With the exception of arsenic and sulphate, water quality criteria applicable for stock watering purposes are expected to be met in the Frasers pit lake at all times following closure. The conservative nature of the model is also likely to result in an over-estimation of contaminant concentrations in Frasers Pit lake (Appendix D).

An aeration system and an aerobic wetland could be installed for the purpose of removing iron and arsenic from the water before it is discharged to Frasers Pit. The simulations of the Frasers Pit lake water quality do not however take into account removal of arsenic and iron by this means and its addition to the suite of mitigation measures would bring pit water quality within stock water limits for arsenic as well.

While sulphate concentrations may exceed stock watering limits within Frasers Pit, the lake is unlikely to be used for stock watering due to limited access created by steep side slopes, fencing and signage. If stock watering is considered a goal for the pit lake passive treatment methods as discussed in Section 7.0 of the main report can be implemented, potentially by placement of the BCR in the Frasers Underground. At this stage, treatment for sulphate is not included in the preferred suite of measures discussed in Section 7.0 of the main report because the costs of implementation are considered impractical compared to the benefit since use of the pit lake for stock watering is considered unlikely. However, pumping of flows to Frasers pit is considered a preferred option for managing TSF drain discharges because it has the least impact on the wider area, internalises MIW, and allows potential effect to be controlled through fencing and other land use controls.

## 1.2 Permanent Diversion of Discharges to Frasers Pit

An extension of the water quality mitigation measure (Section 5.3.1 of the mine report) takes into account the assumption that drainage water from the TTTSF can be injected to the Frasers underground mine without pumping. This management concept is based on the installation of an engineered injection well from the proposed Tipperary sump down to the Frasers Underground mine workings and injecting all TTTSF drainage discharges and captured seepage flows upstream from the sump through this drillhole. The ground surface at the proposed sump location has an elevation of approximately 480 mRL, which is considerably higher than the projected water level in Frasers Pit at a date 150 years following closure. An evaluation of the Frasers Pit filling rate and projected pit lake water quality is presented in Appendix E to this report.

This permanent injection of tailings water to the underground workings would have a minimal effect on the availability of surface water in Tipperary Creek following closure of the mine. Following closure the surface of the TTTSF is to be rehabilitated and run-off from the rehabilitated surface is to be redirected back into Tipperary Creek. Rainwater infiltrating to the TTTSF is expected to do so at a rate of approximately 32 mm/year, which is equivalent to the background rate for the region. Much, but not all, of this infiltrating water would be captured by the proposed long term water management system for the TTTSF. This water management system includes the capture of groundwater seepage discharging to the main channel of Tipperary Creek in the first 300 m downstream from the toe of the TTTSF embankment. The remaining infiltrating rainfall would eventually discharge to creeks surrounding the TTTSF.

# 2.0 TIPPERARY CREEK BASE FLOW AUGMENTATION

## 2.1 Fresh water dam in Tipperary catchment

### 2.1.1 Introduction

A fresh water dam could be constructed in the Tipperary catchment to augment base flows in Tipperary Creek. The concept is for the dam to provide improved downstream water quality by lowering the risk of occurrence of critical low flows through the water course during the summer season. Two dam scenarios have been incorporated into variants of the site wide surface water model.

Scenario 1 incorporates a small fresh water dam (Figure 8 of the main body of this report) located a short distance downstream from the TTTSF embankment. This scenario has a very limited run-off catchment. Provided the storage volume for the dam is 600,000 $m^3$, which is the maximum available at this site, a constant release rate of approximately 2 L/s could be provided.

Scenario 2 incorporates a larger dam lower in the catchment (Figure 8 of the main body of this report), located on neighbouring property beyond the southern boundary of land owned by OceanaGold. The dam reservoir covers a maximum area of around 700,000 $m^2$ and fills to a maximum volume of around 22 $Mm^3$ before overtopping. The design height of the dam face is 75 m above the stream bed. On the basis of this design a constant release rate of approximately 29 L/s could be provided.

The modelling approach and key assumptions are the same as described for fresh water dam modelling in Appendix B attached to the main report.

### 2.1.2 Scenario 1 – Tipperary Creek Small Fresh Water Dam

The Tipperary Creek small fresh water dam is located at the proposed Tipperary Sump location, immediately downstream of the TTTSF, and has a very small catchment area. It is therefore assumed that additional water would need to be sourced to enable this dam to meet the objective of providing a base flow sufficient to dilute contaminants in water released from the TTTS and thereby meet proposed compliance criteria in the Tipperary Creek. The source of the additional flow would presumably be from the Taieri River.

The maximum impounded water volume is calculated to be approximately 700,000 $m^3$, with a maximum surface area of approximately 70,000 $m^2$. These values are based on a dam height of 30 m. The dam bathymetry has been calculated using GIS and dam volume, dam surface area and dam height relationships have been calculated (Table D1). A modified version of the mine water management model for the MGP has been developed incorporating the small freshwater dam on Tipperary Creek following mine closure in 2019. Inflows to this dam include:

- Small undisturbed and rehabilitated catchments upstream from the dam.
- The tailings seepage flows from the TTTSF underdrains and embankment drainage systems.

- Groundwater seepages from the TTTSF discharging to the main Tipperary Creek channel within the first 300 m downstream from the TTTSF embankment.

It is assumed that this contaminated groundwater and tailings seepage water would be discharged into the dam and become diluted with the pumped inflow and a small amount of undisturbed catchment runoff. The dam would release water at a constant flow unless a major rainfall event was to lead to an overtopping of the dam. A number of model iterations were run comparing pumped inflows, dam outflows and dam volumes as well as predicted chemistry at TC01. Modelling indicates this conceptual dam design could ensure stock water compliance standards at the TC01 site provided a constant pumped inflow of around 8 L/s was incorporated in the simulation. The model allows the dam to release a maximum of 10 L/s to the lower Tipperary Creek. Modelled inflows to the dam varied between 0 L/s and 1,200 L/s with an average inflow of approximately 12 L/s. The simulated stored water volume in the dam varied between 500 $m^3$ and 700,000 $m^3$ with an average volume of around 500,000 $m^3$. Figure D1 below presents the percentage of time a particular volume in the dam is equalled or exceeded.

**Table D1: Tipperary Creek Scenario 1 volume, area, dam height relationship.**

| Dam height (m)[1] | Volume ($m^3$) | Area ($m^2$) |
|---|---|---|
| 0 | 0 | 0 |
| 5 | 1,600 | 1,000 |
| 10 | 15,000 | 5,000 |
| 15 | 70,000 | 18,000 |
| 20 | 190,000 | 32,000 |
| 25 | 390,000 | 47,000 |
| 30 | 670,000 | 67,000 |

**Note:** 1) Relative to the base of the dam.

### *2.1.2.1 Scenario 2 – Tipperary Creek Large Freshwater Dam*

The proposed Tipperary Creek fresh water dam for Scenario 2 is located at grid reference -45.38346, 170.50808 and is actually located on a neighbouring property to land owned by OceanaGold. The dam reservoir (when full) covers a maximum surface area of around 700,000 $m^2$ and has a potential maximum storage capacity of approximately 22 $Mm^3$. The design height of the dam face is 75 m above the stream bed. The dam bathymetry has been calculated using GIS and dam volume, dam surface area and dam height relationships have been calculated (Table D2). A modified version of the mine water management model for the MGP site has been developed incorporating a freshwater dam on Tipperary Creek following the mine closure in 2019. Inflows to this dam include:

- Run-off from undisturbed and rehabilitated catchments upstream from the dam.
- The tailings seepage flows from the TTTSF underdrains.
- Groundwater seepages associated with the TTTSF and Frasers East/South WRS's.

It is assumed that this contaminated groundwater and tailings seepage water would be discharged into the dam and diluted with undisturbed catchment runoff prior to discharge to the lower Tipperary Creek. A number of model iterations were run to optimise the dam outflows to meet the TC01 stock water compliance criteria. The dam itself is actually located downstream from the proposed TC01 compliance site and for this reason the water quality was optimised at the dam outflow. Modelling indicates this dam could support a constant discharge to the Tipperary Creek of up to 29 L/s without the dam completely emptying.

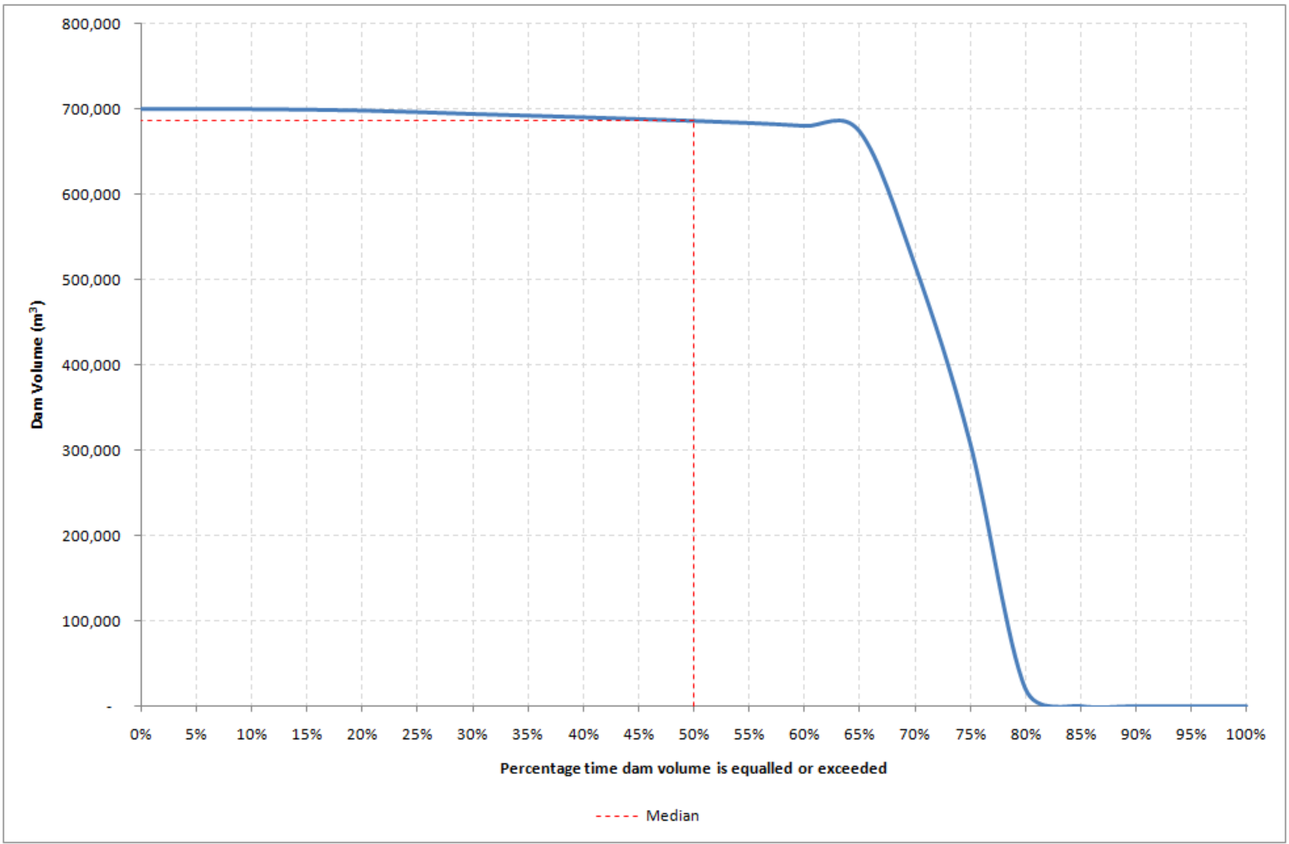


*Figure D1: Small Tipperary Dam volume as a function of time.*

The simulation indicated the reservoir would not completely fill over the modelled period. The maximum stored volume of water was approximately 12 $Mm^3$ or to approximately 60 m of dam height at the outflow. Inflows to the dam varied between 2 L/s and approximately 7,600 L/s, with an average inflow of around 34 L/s. Figure D2 below presents the percentage of time a particular volume in the dam is equalled or exceeded.

**Table D2: Tipperary Creek Scenario 2 volume, area, dam height relationship.**

| Dam height (m)[1] | Volume ($m^3$) | Area ($m^2$) |
|---|---|---|
| 0 | 0 | 0 |
| 10 | 29,000 | 23,000 |
| 20 | 675,000 | 100,000 |
| 30 | 1,880,000 | 144,000 |
| 40 | 3,880,000 | 250,000 |
| 50 | 6,850,000 | 347,000 |
| 60 | 11,400,000 | 563,000 |
| 70 | 17,600,000 | 665,000 |
| 75 | 21,000,000 | 693,000 |

[1] Relative to the bottom of the dam

### 2.1.2.2 Tipperary Creek Freshwater Dam Water Quality Outputs

The water quality outcomes for the above Tipperary Creek freshwater dam scenarios are summarised in Table D3 and Table D4. The small upstream freshwater dam scenario would not achieve sulphate compliance at TC01 without an augmentation flow of 8 L/s. The larger downstream dam model indicates a sulphate would be effectively mitigated at TC01 without augmentation. The same results are not likely for the downstream compliance point in the Shag River with the simulated 99$^{th}$ percentile concentrations for arsenic and sulphate actually increasing. This latter result is primarily due to these contaminants being stored in the dam and released as a near constant mass load to Tipperary Creek downstream. When flows in the Shag River are low, the simulated mass load from Tipperary Creek leads to a higher percentage of non-compliance with the water quality criteria.

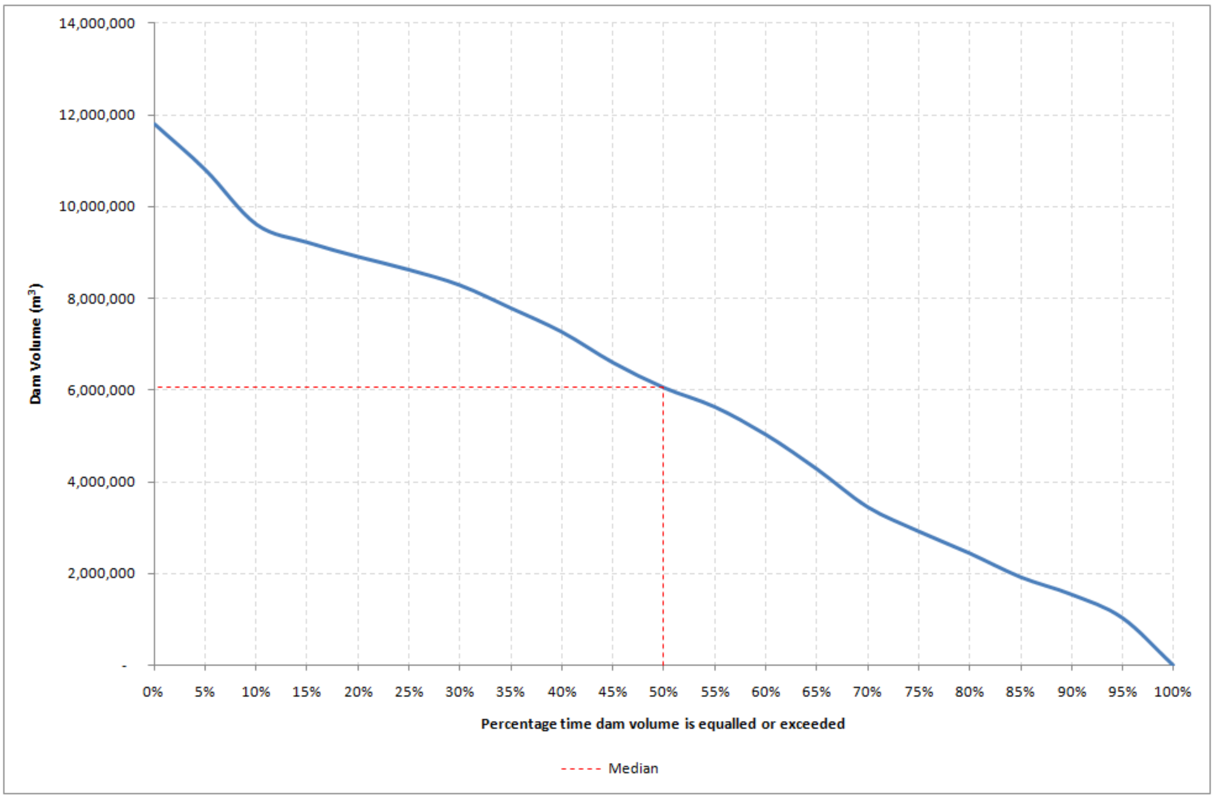


*Figure D2: Lower Tipperary Dam volume as a function of time.*

**Table D3: Projected 99$^{th}$ percentile concentrations for arsenic with Tipperary Creek freshwater dam (operational and closure stages).**

| Model Run (1) | Dam Flow Rates | TC01 | Shag @ McCormicks |
|---|---|---|---|
| Unmitigated | N/A | 0.16 | 0.044 |
| Scenario 1: Tipperary Dam upstream (with augmentation) | Release rate: 10 L/s<br>Augmentation rate: 8 L/s | 0.09 | - |
| Scenario 2: Tipperary Dam downstream (without augmentation) | Release rate: 29 L/s | 0.07(2) | 0.05 |

**Notes:** 1) All units g/m$^3$ unless otherwise stated.
2) Simulated monitoring point defined as the downstream toe of the dam.

### 2.1.3 Passive water treatment systems

The passive treatment systems can be applied to treat the combined drain and seepage water from the TTTSF requiring mitigation. Passive treatment, as described in Section 4.2.2 of the main body of this report, provides a range of options for reducing contaminant concentrations in water draining and seeping from the TTTSF.

**Table D4: Projected 99th percentile concentrations for sulphate with Tipperary Creek freshwater dam (operational and closure stages).**

| Model Run | Dam Flow Rates | TC01 | Shag @ McCormicks |
|---|---|---|---|
| Unmitigated | N/A | 1,000 | 290 |
| Scenario 1: Tipperary Dam upstream (with augmentation) | Release rate: 10 L/s<br>Augmentation rate: 8 L/s | 630 | - |
| Scenario 2: Tipperary Dam downstream | Release rate: 29 L/s | 620(2) | 350 |

**Notes:** 1) All units $g/m^3$ unless otherwise stated.
2) Simulated monitoring point defined as the downstream toe of the dam.

Reductions of TSF drain and groundwater seepage discharge concentrations for arsenic and sulphate by 75% to 90% has been shown through surface water modelling to be likely to achieve existing and proposed compliance criteria on Tipperary Creek. Modelled contaminant concentrations in the Shag River at the McCormicks monitoring point are projected to achieve the compliance limits with passive treatment to a level of 90% contaminant removal. A summary of the modelled geochemical outcomes for arsenic and sulphate are summarised on Table D5 and Table D6.

**Table D5: Projected 99th percentile concentrations with passive treatment for arsenic, Tipperary Creek (operational and closure stages).**

| Model Run (1) | TC01 | Shag @ McCormicks |
|---|---|---|
| Unmitigated | 0.16 | 0.044 |
| 75% Mitigation TSF Drains and GW Seepage | 0.042 | 0.015 |
| 90% Mitigation TSF Drains and GW Seepage | 0.019 | 0.009 |

**Note:** 1) All units $g/m^3$ unless otherwise stated.
2) Passive treatment only applied during closure stage in model as discharges are pumped to mine process water or Frasers Pit during operational stages and first 20 years of post closure stage.

**Table D6: Projected 99th percentile concentrations with passive treatment for sulphate, Tipperary Creek (operational and closure stages).**

| Model Run (1) | TC01 | Shag @ McCormicks |
|---|---|---|
| Unmitigated | 1,000 | 290 |
| 75% Mitigation TSF Drains and GW Seepage | 570 | 190 |
| 90% Mitigation TSF Drains and GW Seepage | 560 | 170 |

**Note:** 1) All units $g/m^3$ unless otherwise stated.
2) Passive treatment only applied during closure stage in model as discharges are pumped to mine process water or Frasers Pit during operational stages and first 20 years of post closure stage.

# APPENDIX E

## Combined Mitigation Option

# 1.0 COMBINED SUITE OF OPTONS FOR WATER QUALITY EFFECTS MITIGATION

## 1.1 Summary of Mitigation Options Suite

### 1.1.1 Pump TSF decant and drain water to Frasers Pit for 20 years

At closure of the MGP site, existing water management plans require that remaining water in the TSF decant ponds is pumped down and disposed of (Kingett Mitchell 2005). The mine schedule for the Macraes Phase III Project allows the decant water from the MTI and the SPI to be recovered to the mine water management system during the operational period of the mine. Decant water would however remain on the TTTSF at the close of operations. It is planned to pump this water to Frasers Pit following close of the mine to enable capping and rehabilitation of the TTTSF to proceed.

Tailings water discharges from the SPI and the MTI are expected to decline rapidly following closure of these facilities. The existing mine water management plan allows for an initial period of pumping of these discharges to Frasers Pit following closure of the mine. Under the Macraes Phase III Project, these facilities would close and be rehabilitated several years prior to the close of the wider MGP operations. During this period discharge water from the MTI and the SPI would be recovered to the process water system. At the close of MGP operations the simulation incorporates a period of up to 20 years during which these discharges are pumped to Frasers Pit. This period is an extremely conservative projection. It is possible that other mitigation measures could be introduced at the time of site closure to manage the water quality in Deepdell Creek without the necessity of pumping the MTI water back to Frasers Pit.

### 1.1.2 Permanent diversion of TTTSF discharges to Frasers underground mine

Following closure of the MGP site, rehabilitation planning requires that the remaining water in TSF decant ponds is pumped down and disposed of (Kingett Mitchell 2005). During the initial post-closure period it is expected that discharges from the TTTSF drain systems would be large and the water quality too poor to be directly released to Tipperary Creek. The current post-closure MGP site management plan incorporates pumping of TSF decant and drain discharge water for an initial period to Frasers Pit.

Water management modelling of the MGP has incorporated a base case assumption that decant water from the TTTSF would be pumped to Frasers Pit for a period of 20 years following closure of the MGP. Modelling of pit filling rates indicates that Frasers Pit is very unlikely to overflow within a 150 year period following closure of the site. The pumping of the TTTSF decant pond and TSF drain discharges to Frasers Pit for a period of up to 20 years does not change this outcome.

An expansion of the water quality mitigation measure proposed above is based on the assumption that drainage water from the TTTSF and groundwater transporting contaminants from the Frasers West WRS can be diverted to Frasers Pit or Frasers underground mine without pumping. This management concept is based on the drilling from the proposed Tipperary sump down to the Frasers Underground mine workings and injecting all TTTSF drainage discharges and captured seepage flows upstream from the sump through this drillhole. For modelling purposes it has been assumed that the drainage water is injected to the underground workings without pre-treatment. The ground surface at the proposed sump location has an elevation of approximately 480 mRL, which is well above the projected water level in Frasers Pit at a date 150 years following closure (Golder 2011c).

There is also a perceived need to manage groundwater discharges from the Frasers West WRS and water from the Murphys Creek silt pond in order to meet water quality compliance limits in those catchments. Diverting the flows from these areas into Frasers Pit on a permanent basis could offer a management option.

It is potentially feasible to construct a drainage system to capture shallow groundwater down-gradient from the Frasers West WRS in the NBWR catchment. Additionally, installation of a drain around the southern side of the proposed Frasers South WRS with discharge to the existing backfill in the Golden Ridge Pit (Southern appendix of Frasers Pit) would limit new net effects on the water quality of the Murphys Creek catchment.

### 1.1.3 Passive treatment of TTTSF and WRS seepage to Frasers and Round Hill Pit lakes

Passive treatment systems could be established on hillsides or within pit benches to treat diverted discharges for arsenic and iron prior to the discharge water being released to the pit lakes. Although active release of TSF drainage water to Round Hill Pit has not been included in the proposed water management measures for the MGP, seepage losses to Round Hill Pit from the SPI and the MTI will occur. Where these seepages can be collected through pit wall drainage systems or discharge collection zones the water can be treated passively.

An iron-arsenic aerobic cell comprised of aerating systems and a reed bed populated by wetland plant species would remove arsenic and iron prior to discharge to the pit lake. It is expected that $\text{cyanide}_{WAD}$ concentrations in the discharge water would also be considerably reduced by this treatment process. The final location and construction of aerobic cells would be dependent on the final pit landform.

Sulphate concentrations in the TSF discharge water would not be substantially reduced by an aerobic treatment system. Although sulphate concentrations could be expected to exceed a concentration of 1,000 $g/m^3$ in the pit lake water for both pits over the short to medium term, the simulated concentrations decrease to below this level over the long term. The time required for a long term steady state water quality to be reached depends on numerous factors including the period of active discharge of MTI drainage water to Frasers Pit following closure.

Other contaminants are not considered likely to exceed compliance levels in the pit lakes.

### 1.1.4 Passive treatment of MTI/SPI seepage to Deepdell Creek

Passive treatment is a viable option for reducing concentrations of water draining and seeping from the MTI/SPI areas which may be applied once the initial discharge flows have decreased to the extent that the size of the treatment plant is acceptable. Passive treatment systems could be established close to Maori Tommy gully.

An iron-arsenic aerobic cell comprised of a reed bed populated by wetland plant species would remove arsenic and iron prior to discharge to Deepdell Creek. Sulphate concentrations would not be reduced through this system and therefore would be mitigated through a continuous baseflow supplied by the proposed Camp Creek freshwater dam.

### 1.1.5 Camp Creek fresh water dam

The construction of a fresh water dam in Camp Creek, part of the Deepdell Creek catchment upstream from the Maori Tommy Gully confluence, helps to mitigate non-point source water quality issues by providing greater base flow reliability. Run-off collected during periods of higher precipitation could be stored in the dam and released as a constant discharge throughout the year, thus supplementing base flows in the creek. By decreasing the frequency of critical low flows, the risk of non-compliance with consented water quality limits is reduced.

Modelling of the Camp Creek freshwater dam scenario indicates that a maximum constant discharge rate of 10 L/s could be maintained by the dam and its filling time would be approximately 2 to 8 years, depending on levels of precipitation during the filling period. Should a discharge management system be installed at Camp Creek, the flows released on a periodic basis for base flow augmentation could be substantially greater.

Further details on the assessment and modelling of the proposed Camp Creek freshwater dam are provided in Appendix B.

## 1.2 Combining Fresh Water Dams with Passive Treatment

A simulated combination of the following measures has shown the water quality would be effectively mitigated at monitoring points in the Shag River catchment:

- A freshwater dam on either Deepdell Creek or Camp Creek to manage sulphate concentrations,
- Passive aerobic treatment of TSF discharge water to remove 90% of the dissolved arsenic and iron in the collected drainage and seepage water from the TSF's, with the added benefit of increased attenuation of cyanide$_{WAD}$.
- Removal of the MTG silt dam.

A summary of the results for arsenic and sulphate is presented in Table E1and Table E2.

**Table E1: Results of projected arsenic concentrations for combined mitigation measures (freshwater dam and passive treatment, operational and closure stages).**

| Model Run (1) | Dam Flow Rates | DC08 | Shag @ Loop | Shag @ McCormicks | TC01 |
|---|---|---|---|---|---|
| 75% mitigation TSF drains, and Camp Creek dam (MTG removed after closure) | Release rate: 24 L/s Augmentation rate: 15 L/s | - | 0.01 | 0.01 | - |
| 90% mitigation TSF drains and seepage and Deepdell Creek dam | Release rate: 26 L/s | 0.02 | | | 0.02 |
| 90% mitigation TSF drains and seepage, Camp Creek dam (MTG silt pond removed) | Release rate: 7 L/s | 0.03 | 0.01 | 0.01 | 0.02 |

**Note:** 1) All units g/m$^3$ unless otherwise stated.

**Table E2: Results of projected sulphate concentrations for combined mitigation measures (freshwater dam and passive treatment, operational and closure stages).**

| Model Run (1) | Dam Flow Rates | DC08 | Shag @ Loop | Shag @ McCormicks | TC01 |
|---|---|---|---|---|---|
| 75% mitigation TSF drains, and Camp Creek dam (MTG removed after closure) | Release rate: 24 L/s Augmentation rate: 15 L/s | - | 130 | 140 | - |
| 90% mitigation TSF drains and seepage and Deepdell Creek dam | Release rate: 26 L/s | 320 | - | - | 560 |
| 90% mitigation TSF drains and seepage, Camp Creek dam (MTG silt pond removed) | Release rate: 7 L/s | 510 | 170 | 160 | 560 |

**Note:** 1) All units g/m$^3$ unless otherwise stated.

## 1.3 Combining Groundwater Seepage Interception with Fresh Water Dam and Passive Treatment

A surface water model run was undertaken to evaluate the level of compliance that could be achieved taking into account combined suite of mitigation options described above and summarised as:

- Injection of TTTSF drain and groundwater seepage to the Frasers Underground mine, which would eventually discharge to Frasers Pit.
- Diversion of groundwater seepages to the silt dams from the NBWR catchments to the Frasers Pit. Operationally this would require gravity drains to channel these water sources to the pit.
- Diversion of Frasers South WRS seepage to the existing backfill in the Golden Ridge Pit (Southern appendix of Frasers Pit)Passive treatment through aerobic wetlands of TSF and WRS drain seepages and groundwater prior to discharge to the Deepdell Creek catchments and pit lakes.
- Installation of a fresh water dam on Camp Creek.
- Removal of the Maori Tommy Gully silt dam.

Reductions of TSF drain and groundwater seepage discharge concentrations for arsenic by 90% has been shown through surface water modelling to be likely to achieve existing and proposed compliance criteria on Deepdell Creek and the Shag River.

Sulphate from WRS discharges contributes significantly to the total sulphate concentrations measured at the DC08 and Shag compliance points. Sulphate concentrations at the Shag River compliance points could be mitigated through provision of continuous or managed baseflows from the Camp Creek fresh water dam. In addition, the sulphate concentrations at the proposed TC01 and McCormicks compliance points could be managed through injection of the drainage and some seepage water from the TTTSF to Frasers Pit.

In terms of water volumes and water levels in Frasers Pit, the model indicates the pit would not overflow within the 150 post-closure modelled period (Figure E1 and Figure E2). In these projections, the volume of the pit includes that of Innes Mills Pit, which is expected to be hydraulically connected to Frasers Pit following site closure.

The projected water quality outputs for the 150 year model period are summarised in Table E3 to Table E16. The water quality criteria applicable to the Frasers Pit lake (Consent No. 2007.583) following overflow are arsenic (0.19 g/m$^3$), copper (0.011 g/m$^3$), lead (0.0025 g/m$^3$) and pH (6.0 – 9.5). With the exception of sulphate and arsenic, these criteria are expected to be met in Frasers pit. The conservative nature of the model is likely to result in an over-estimation of contaminant concentrations in Frasers Pit. The pit lake is expected to require in excess of 150 years to fill. During this period it is expected that the arsenic in the TSF water discharged directly to the lake would have become mostly oxidised and no longer be available for transport in solution.

The primary mitigation measure of pumping TSF decant and drain water to Frasers Pit for an initial post-closure period appears to be acceptable since neither groundwater nor surface water discharges are expected to occur from the lake at least within the modelled period. In addition, the water quality in the pit lake improves over time due to the increasing component of dilution water in the lake.

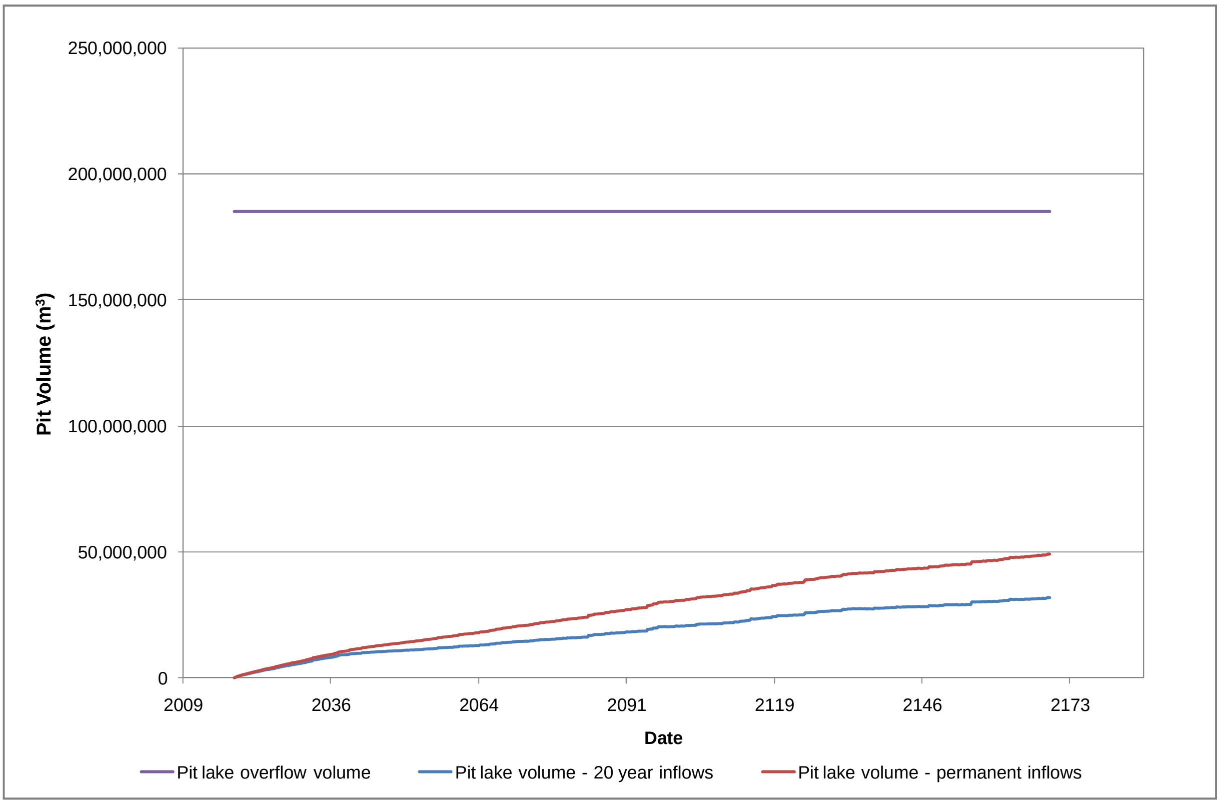


*Figure E1: Frasers Pit lake post-closure volume projections compared to the pit overflow volume.*

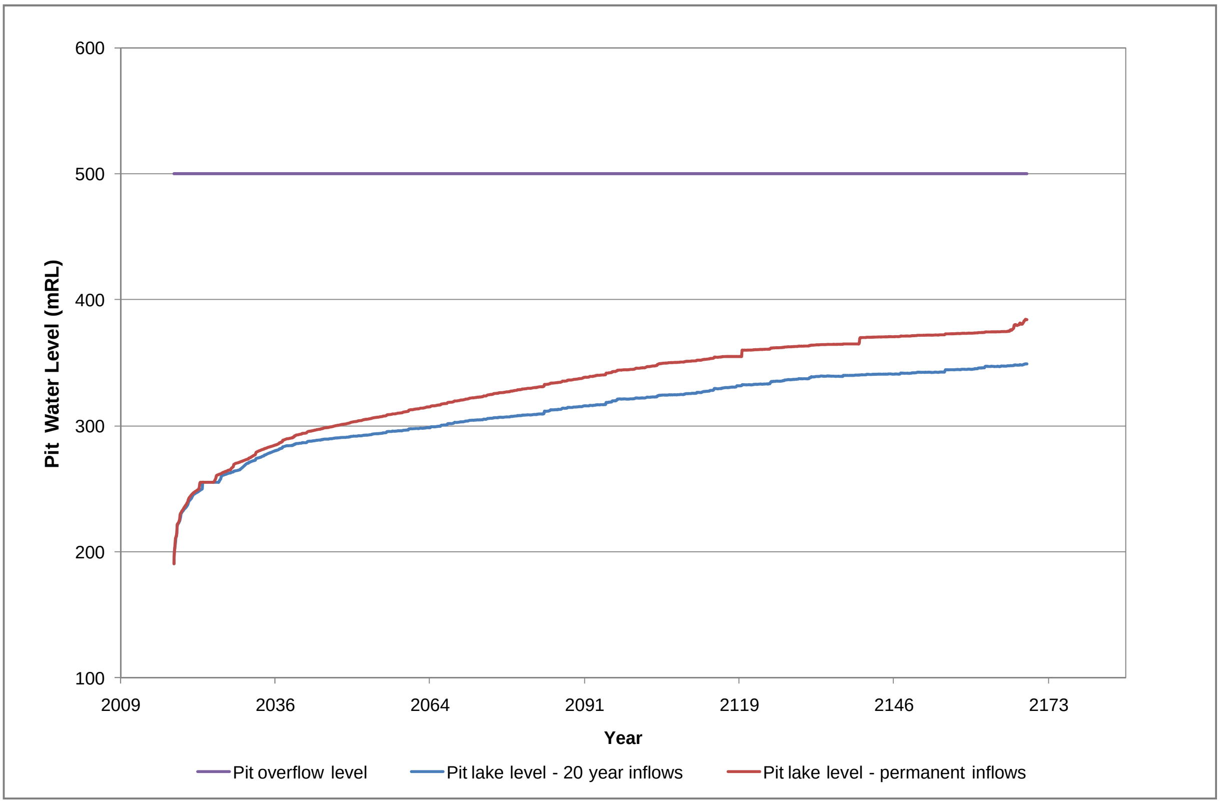


*Figure E2: Frasers Pit lake post-closure water level projections compared to the pit overflow level.*

The quality of the water discharging from TSF drainage systems indicates the reducing geochemical conditions are present in the stored tailings at the site. Following site closure the TSF drainage discharges may be pumped to Frasers Pit and injected into the closed Frasers underground mine. It is expected that the closed mine would have been sealed and the atmosphere in the mine would have become progressively more oxygen poor following closure. In order to ensure the water injected to the underground workings remains under reducing conditions following injection, preparation of the receiving area may be undertaken prior to mine closure. This preparation may include storage or organic material in the underground workings, which would react with the available oxygen following closure and thereby maintain the reducing environment. In addition, management of the water quality should be able to be encourage the production and precipitation of metal sulphides within the underground workings.

Under post-closure groundwater conditions the flow of water through the underground workings is expected to be very slow. On that basis a large proportion of the TSF water discharged to these workings could be expected to stay in the underground workings for a long time.

**Table E3: Summary of projected water quality at Frasers Pit (operational and closure stages).**

| Parameter (1) | Minimum | Mean | 95th Percentile | 99th Percentile | Maximum |
|---|---|---|---|---|---|
| Arsenic | 0.04 | 0.96 | 1.6 | 1.66 | 1.6 |
| Sulphate | 210 | 1,800 | 2,110 | 2,140 | 2,150 |

**Note:** 1) All units g/m$^3$ unless otherwise stated.
2) Based on model run with Camp Creek Dam and TTTSF and Frasers West WRS groundwater seepage to Frasers Pit.

**Table E4: Summary of projected water quality in Frasers Pit – post-closure (post 2036).**

| Parameter (1) | Minimum | Mean | 95th Percentile | 99th Percentile | Maximum |
|---|---|---|---|---|---|
| Arsenic | 0.8 | 1.0 | 1.5 | 1.6 | 1.6 |
| Sulphate | 1,700 | 2,000 | 2,100 | 2,100 | 2,100 |
| $Cyanide_{WAD}$ | 0.13 | 0.21 | 0.24 | 0.25 | 0.25 |
| Copper | 0.004 | 0.005 | 0.005 | 0.005 | 0.005 |
| Iron | 4.9 | 8.3 | 9.9 | 10 | 10 |
| Lead | <0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Sodium | 200 | 230 | 250 | 250 | 250 |
| Potassium | 0.02 | 18 | 21 | 21 | 22 |
| Calcium | 64 | 350 | 380 | 390 | 390 |
| Magnesium | 0.02 | 200 | 220 | 220 | 220 |
| Zinc | 0.02 | 0.020 | 0.02 | 0.02 | 0.02 |
| Chloride | 24 | 35 | 40 | 41 | 41 |

**Note:** 1) All units g/m$^3$ unless otherwise stated.
2) Based on model run with Camp Creek Dam and TTTSF and Frasers West WRS groundwater seepage to Frasers Pit.

**Table E5: Summary of projected water quality Shag River at Loop Road (operational and closure stages).**

| Parameter (1) | Minimum | Mean | 95th Percentile | 99th Percentile | Maximum |
|---|---|---|---|---|---|
| Arsenic | 0.002 | 0.004 | 0.008 | 0.01 | 0.03 |
| Sulphate | 4 | 70 | 190 | 270 | 500 |

**Note:** 1) All units g/m$^3$.
2) Based on model run with Camp Creek Dam in place and 90% passive treatment of MTI drain discharges for arsenic; sulphate outcomes are based on the model run for Camp Creek Dam.

**Table E6: Summary of projected water quality in Shag River at Loop Road – post-closure (post 2036).**

| Parameter | Minimum | Mean | 95th Percentile | 99th Percentile | Maximum |
|---|---|---|---|---|---|
| Arsenic | 0.002 | 0.004 | 0.009 | 0.01 | 0.02 |
| Sulphate | 5 | 80 | 210 | 290 | 500 |
| $Cyanide_{WAD}$ | 0.003 | 0.005 | 0.009 | 0.012 | 0.018 |
| Copper | <0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Iron | 0.14 | 0.3 | 0.3 | 0.4 | 0.6 |
| Lead | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Sodium | 4.7 | 13 | 15 | 17 | 21 |
| Potassium | 0.002 | 1.2 | 1.6 | 1.9 | 2.6 |
| Calcium | 7 | 21 | 36 | 45 | 70 |
| Magnesium | 0.002 | 11 | 23 | 30 | 51 |
| Zinc | 0.002 | 0.005 | 0.006 | 0.007 | 0.009 |
| Chloride | 3 | 11.3 | 12.0 | 12.8 | 14.8 |

**Note:** 1) All units $g/m^3$.
2) Based on model run with Camp Creek Dam in place and 90% passive treatment of MTI drain discharges for arsenic; sulphate outcomes are based on the model run for Camp Creek Dam.

**Table E7: Summary of projected water quality in Shag River at McCormicks (operational and closure stages).**

| Parameter (1) | Minimum | Mean | 95th Percentile | 99th Percentile | Maximum (3) |
|---|---|---|---|---|---|
| Arsenic | 0.002 | 0.003 | 0.007 | 0.009 | 0.03 |
| Sulphate | 4 | 60 | 150 | 210 | 400 |

**Note:** 1) All units $g/m^3$.
2) Based on model run with Camp Creek Dam in place and 90% passive treatment of MTI drain discharges for arsenic; sulphate outcomes are based on the model run for Camp Creek Dam. TTTSF drain discharges diverted to Frasers Undergound.
3) Unlikely to occur.

**Table E8: Summary of projected water quality in Shag River at McCormicks – post-closure (post 2036).**

| Parameter | Minimum | Mean | 95th Percentile | 99th Percentile | Maximum |
|---|---|---|---|---|---|
| Arsenic | 0.002 | 0.004 | 0.007 | 0.009 | 0.02 |
| Sulphate | 146 | 190 | 210 | 220 | 220 |
| $Cyanide_{WAD}$ | 0.003 | 0.005 | 0.007 | 0.009 | 0.014 |
| Copper | <0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Iron | 0.18 | 0.3 | 0.5 | 0.6 | 1.0 |
| Lead | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Sodium | 5.8 | 13 | 16 | 18 | 25 |
| Potassium | 0.5 | 1.2 | 1.5 | 1.7 | 2.3 |
| Calcium | 8.4 | 20 | 32 | 40 | 62 |
| Magnesium | 4 | 9 | 19 | 26 | 44 |
| Zinc | 0.002 | 0.005 | 0.0060 | 0.007 | 0.008 |
| Chloride | 4 | 11 | 11.4 | 11.8 | 13 |

**Note:** 1) All units $g/m^3$. 2) Based on model run with Camp Creek Dam in place and 90% passive treatment of MTI drain discharges for arsenic; sulphate outcomes are based on the model run for Camp Creek Dam. TTTSF drain discharges diverted to Frasers Undergound.

**Table E9: Summary of projected water quality in Tipperary Creek at TC01 (operational and closure stages).**

| Parameter [1] | Minimum | Mean | 95th Percentile | 99th Percentile | Maximum |
|---|---|---|---|---|---|
| Arsenic | <0.001 | 0.002 | 0.005 | 0.009 | 0.05 |
| Sulphate | 0.85 | 280 | 450 | 500 | 500 |

**Note:** 1) All units g/m$^3$. 2) Based on model run Camp Creek Dam and TTTSF and Frasers West WRS seepage to Frasers Pit.

**Table E10: Summary of projected water quality in Tipperary Creek at TC01 – post-closure (post 2036).**

| Parameter | Minimum | Mean | 95th Percentile | 99th Percentile | Maximum |
|---|---|---|---|---|---|
| Arsenic | <0.001 | 0.002 | 0.005 | 0.009 | 0.013 |
| Sulphate | 25 | 300 | 370 | 430 | 500 |
| Cyanide$_{WAD}$ | 0.003 | 0.007 | 0.007 | 0.009 | 0.01 |
| Copper | <0.001 | <0.001 | 0.001 | 0.002 | 0.002 |
| Iron | 0.32 | 1.9 | 2.3 | 2.7 | 3.1 |
| Lead | <0.001 | <0.001 | 0.001 | 0.001 | 0.001 |
| Sodium | 10 | 33 | 37 | 45 | 51 |
| Potassium | 0.004 | 2.3 | 2.4 | 3.0 | 3.2 |
| Calcium | 0.16 | 56 | 65 | 77 | 89 |
| Magnesium | 0.004 | 41 | 48 | 57 | 66 |
| Zinc | 0.004 | 0.007 | 0.007 | 0.009 | 0.01 |
| Chloride | 5.7 | 7.3 | 9.3 | 10.2 | 10.8 |

**Note:** 1) All units g/m$^3$. 2) Based on model run Camp Creek Dam and TTTSF and Frasers West WRS seepage to Frasers Pit.

**Table E11: Summary of projected water quality in Murphys Creek at MC01 (operational and closure stages).**

| Parameter [1] | Minimum | Mean | 95th Percentile | 99th Percentile | Maximum |
|---|---|---|---|---|---|
| Arsenic | <0.001 | 0.006 | 0.01 | 0.01 | 0.1 |
| Sulphate | 150 | 190 | 230 | 270 | 340 |

**Note:** 1) All units g/m$^3$. 2) Based on model run Camp Creek Dam and TTTSF and Frasers West WRS seepage to Frasers Pit.

**Table E12: Summary of projected water quality in Murphys Creek at MC01 – post-closure (post 2036).**

| Parameter | Minimum | Mean | 95th Percentile | 99th Percentile | Maximum |
|---|---|---|---|---|---|
| Arsenic | <0.001 | 0.006 | 0.01 | 0.01 | 0.02 |
| Sulphate | 150 | 190 | 210 | 210 | 220 |
| Cyanide$_{WAD}$ | <0.001 | 0.003 | 0.004 | 0.005 | 0.005 |
| Copper | <0.001 | 0.001 | 0.002 | 0.002 | 0.002 |
| Iron | 0.09 | 0.13 | 0.2 | 0.2 | 0.2 |
| Lead | <0.001 | 0.001 | 0.00092 | 0.00101 | 0.001243 |

| Parameter | Minimum | Mean | 95th Percentile | 99th Percentile | Maximum |
|---|---|---|---|---|---|
| Sodium | 6.5 | 12 | 17 | 18 | 21 |
| Potassium | 0.003 | 2.162 | 2.9 | 3.1 | 3.9 |
| Calcium | 21 | 68.328 | 85 | 88 | 90 |
| Magnesium | 0.003 | 34.538 | 35 | 35 | 42 |
| Zinc | 0.003 | 0.004 | 0.0048 | 0.0052 | 0.0067 |
| Chloride | 1.6 | 6.398 | 9.9 | 10.4 | 10.9 |

**Note:** 1) All units g/m$^3$. 2) Based on model run Camp Creek Dam and TTTSF and Frasers West WRS seepage to Frasers Pit.

**Table E13: Summary of projected water quality in NBWR at NBWRRB (operational and closure stages).**

| Parameter (1) | Minimum | Mean | 95th Percentile | 99th Percentile | Maximum |
|---|---|---|---|---|---|
| Arsenic | <0.001 | 0.004 | 0.009 | 0.016 | 0.17 |
| Sulphate | 5 | 460 | 700 | 700 | 710 |

**Note:** 1) All units g/m$^3$. 2) Based on model run Camp Creek Dam and TTTSF and Frasers West WRS seepage to Frasers Pit.

**Table E14: Summary of projected water quality in NBWR at NBWRRB – post-closure (post 2036).**

| Parameter | Minimum | Mean | 95th Percentile | 99th Percentile | Maximum |
|---|---|---|---|---|---|
| Arsenic | <0.001 | 0.004 | 0.009 | 0.016 | 0.035 |
| Sulphate | 150 | 510 | 700 | 710 | 710 |
| Cyanide$_{WAD}$ | <0.001 | 0.002 | 0.004 | 0.005 | 0.005 |
| Copper | <0.001 | 0.001 | 0.002 | 0.002 | 0.003 |
| Iron | 0.1 | 0.2 | 0.3 | 0.3 | 0.3 |
| Lead | <0.001 | <0.001 | 0.001 | 0.001 | 0.002 |
| Sodium | 17 | 18 | 18 | 19 | 31 |
| Potassium | <0.001 | 3.6 | 3.9 | 3.9 | 6.0 |
| Calcium | 1.5 | 120 | 130 | 130 | 130 |
| Magnesium | <0.001 | 80 | 110 | 110 | 110 |
| Zinc | <0.001 | 0.002 | 0.0045 | 0.0054 | 0.0096 |
| Chloride | 3.3 | 6.0 | 10.0 | 10.6 | 14.7 |

**Note:** 1) All units g/m$^3$. 2) Based on model run Camp Creek Dam and TTTSF and Frasers West WRS seepage to Frasers Pit.

**Table E15: Summary of projected water quality in NBWR at NB03 (operational and closure stages).**

| Parameter (1) | Minimum | Mean | 95th Percentile | 99th Percentile | Maximum |
|---|---|---|---|---|---|
| Arsenic | <0.001 | 0.01 | 0.01 | 0.01 | 0.07 |
| Sulphate | 12 | 170 | 190 | 210 | 300 |

**Note:** 1) All units g/m$^3$. 2) Based on model run Camp Creek Dam and TTTSF and Frasers West WRS seepage to Frasers Pit.

**Table E16: Summary of projected water quality in NBWR at NB03 – post-closure (post 2036).**

| Parameter | Minimum | Mean | 95th Percentile | 99th Percentile | Maximum |
|---|---|---|---|---|---|
| Arsenic | 0.008 | 0.01 | 0.01 | 0.01 | 0.01 |
| Sulphate | 150 | 170 | 190 | 210 | 300 |
| $Cyanide_{WAD}$ | 0.004 | 0.005 | 0.005 | 0.005 | 0.005 |
| Copper | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| Iron | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Lead | <0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Sodium | 18 | 18 | 18 | 18 | 19 |
| Potassium | 0.004 | 3 | 3 | 3 | 3.2 |
| Calcium | 8 | 90 | 90 | 100 | 100 |
| Magnesium | 0.004 | 36 | 39 | 42 | 54 |
| Zinc | 0.004 | 0.005 | 0.005 | 0.005 | 0.005 |
| Chloride | 9 | 11 | 11 | 11 | 11 |

**Note:** 1) All units g/m$^3$. 2) Based on model run Camp Creek Dam and TTTSF and Frasers West WRS seepage to Frasers Pit.

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# APPENDIX F

## Comparison of Modelled Options

A preferred mitigation approach to the effects of the Macraes Gold project on receiving water quality has been identified. This approach involves providing water quality management options which are effective in meeting water quality goals, feasible to implement concurrent with mining operations, reasonable capital costs and require little to no active maintenance in the post closure phase. A modifying consideration is also the ease in which consent can be acquired.

The effectiveness of a mitigation option is primarily measured by whether compliance with proposed arsenic and sulphate criteria are achieved at the water quality compliance points in Deepdell Creek, Tipperary Creek, the NBWR and the Shag River. A summary of the predicted changes in water quality for those options that were incorporated into the site wide surface water model is presented in Table F1 (arsenic) and Table F2 (sulphate). Additionally, these tables present the results of several of the mitigation options in combination. The tables report the 99$^{th}$ percentile of the model results, which is considered the appropriate value for comparison with compliance limits as discussed in Section 2.8 of the main body of this report. Maintaining water quality below the 99$^{th}$ percentile is indicative of a monitoring location where water quality is effectively mitigated.

The conservative assumptions in the water management model are likely to over-estimate projected arsenic values (Golder 2011c). Table F1 shows the relative decreases in arsenic produced by the investigated mitigation measures. Although some of the resulting concentrations from the simulation are above the compliance limits, these concentrations are very unlikely to be observed in actuality due to natural attenuation of arsenic when transported in surface water bodies.

Sulphate is not subject to the same degree of natural attenuation due to precipitation and adsorption as arsenic. Sulphate is likely to stay in solution when reaching the surface water bodies. However, conservative aspects of the surface water model related to the simulation of dry periods at the site indicate the maximum concentrations generated by the simulations are unlikely to be observed, especially at the Shag River. This conclusion is further supported by historical periods where sulphate was observed to be elevated or above compliance limits in Deepdell Creek but a corresponding degree of increase in concentration was not observed in the Shag River at the Loop Road compliance point.

The 99$^{th}$ percentile is considered to be a useful indicator of the water quality that may be expected in the receiving water bodies. Monitoring of trends throughout the operations period is an appropriate means to confirm the conservatism within the surface water model.

Individual mitigation scenarios with freshwater dams without augmentation or passive treatment of TSF discharges (drains and groundwater seepage) are considered to be suitable to achieve the mitigation objectives for specific receiving water bodies. When freshwater dams such as the Camp Creek Dam are augmented with water from the Taieri or other source, the risk of non-compliance is decreased. However, long-term pumping after mine closure is not a preferred mitigation option.

Simulation of a freshwater dam constructed in Deepdell Creek with constant discharge flows indicates water quality would be effectively mitigated in Deepdell Creek and the Shag River. However, consultation with stakeholders indicated placement of a dam on Deepdell Creek is not a preferred option. A freshwater dam constructed on Camp Creek with a constant discharge of 7 L/s, combined with passive treatment of TSF discharge water, is also considered likely to achieve compliance with the water quality criteria in Deepdell Creek and in the Shag River at Loop Road. A fresh water dam on Highlay Creek with a constant discharge has been simulated, however this dam alone is unlikely to be able to provide a continuous discharge sufficiently large to achieve the mitigation objectives.

Active management of discharges from the Camp Creek dam could be applied, whereby winter discharges are minimised in favour of higher discharges during the low flow summer periods. Although this option is expected to be practically achievable, it would involve ongoing maintenance and monitoring. At this stage of the investigation, it is considered likely that water quality in Deepdell Creek and in the Shag River at Loop Road would be effectively mitigated with instigation of a freshwater dam in Camp Creek dam combined with aerobic passive treatment of drain discharge water from the MTI.

**Table F1: Comparison of mitigation runs: projected 99th percentile concentrations for arsenic (operational and closure stages).**

| **Model Run** (1) | **Dam Flow Rates** | **DC08** | **Shag @ Loop** | **Shag @ McCormicks** | **TC01** |
|---|---|---|---|---|---|
| Compliance limits | N/A | 0.15 | 0.01 | 0.01 | 0.15 |
| Unmitigated | N/A | **0.20** | **0.044** | **0.044** | **0.16** |
| **Mitigation run for individual components** | | | | | |
| Camp Creek dam | Release rate: 7 L/s | 0.14 | **0.04** | - | - |
| Deepdell Creek dam | Release rate: 26 L/s | 0.09 | **0.03** | - | - |
| Tipperary Dam upstream, with augmentation | Release rate: 10 L/s<br>Augmentation rate: 8 L/s | - | - | - | 0.09 |
| Tipperary Dam downstream, without augmentation | Release rate: 29 L/s | - | - | 0.05 | 0.07(1) |
| 75% mitigation TSF drains and GW seepage | N/A | 0.07 | **0.02** | **0.015** | 0.042 |
| 90% mitigation TSF drains and GW seepage | N/A | 0.05 | 0.01 | 0.009 | 0.019 |
| **Mitigation run for combined components** | | | | | |
| 75% mitigation of TSF drains, Camp Creek dam installed with augmentation, MTG silt dam removed. | Release rate: 24 L/s<br>Augmentation rate: 15 L/s | - | 0.01 | 0.01 | - |
| 90% mitigation of TSF drains and seepage, Deepdell Creek dam installed | Release rate: 26 L/s | 0.02 | | | 0.02 |
| 90% mitigation TSF drains and seepage, Camp Creek dam installed, MTG silt pond removed | Release rate: 7 L/s | 0.03 | 0.01 | 0.01 | 0.02 |
| 90% arsenic mitigation for TSF drains and seepage, Camp Creek dam installed, MTG silt pond removed, diversion of TTTSF drain discharges to Frasers Pit. | Release rate: 7 L/s | 0.03 | 0.01 | 0.009 | 0.009 |

**Notes:** 1) All units $g/m^3$ unless otherwise stated. Values in bold font exceed the compliance criteria.
2) Simulated monitoring point defined as the downstream toe of the dam.

**Table F2: Comparison of mitigation runs: projected 99th percentile concentrations for sulphate (operational and closures stages).**

| **Model Run** (1) | **Dam Flow Rates** | **DC08** | **Shag @ Loop** | **Shag @ McCormicks** | **TC01** |
|---|---|---|---|---|---|
| Compliance limits | N/A | 1,000 | 250 | 250 | 1,000 |
| Unmitigated | N/A | **1,150** | **290** | **290** | **1,000** |
| **Mitigation run for individual components** | | | | | |
| Camp Creek dam | Release rate: 10 L/s | 810 | **270** | - | - |
| Deepdell Creek dam | Release rate: 26 L/s | 520 | 210 | - | - |
| am, with augmentation | Release rate: 10 L/s<br>Augmentation rate: 8 L/s | - | - | - | 630 |
| Tipperary Dam downstream, without augmentation | Release rate: 29 L/s | - | - | **350** | 620 (2) |
| 75% Mitigation TSF drains and GW seepage | N/A | 780 | 210 | 190 | 570 |
| 90% Mitigation TSF drains and GW seepage | N/A | 750 | 190 | 170 | 560 |
| **Mitigation run for combined components** | | | | | |
| 75% mitigation of TSF drains and seepage, Camp Creek dam installed with augmentation, MTG silt dam removed. | Release rate: 24 L/s<br>Augmentation rate: 15 L/s | - | 130 | 140 | - |
| 90% mitigation TSF drains and seepage, Deepdell Creek dam installed, MTG silt pond removed | Release rate: 26 L/s | 320 | - | - | 560 |
| 90% mitigation TSF drains and seepage, Camp Creek dam installed, MTG silt pond removed | Release rate: 10 L/s | 510 | 170 | 160 | 560 |
| 90% arsenic mitigation TSF drains and seepage, Camp Creek dam installed, MTG silt pond removed, diversion of TTTSF drain discharges to Frasers Pit. | Release rate: 10 L/s | 810 | **270** | 210 | 500 |
| 90% arsenic mitigation TSF drains and seepage, Camp Creek dam with staged release, MTG silt pond removed, diversion of TTTSF drain discharges to Frasers Pit. | Release rate: 16 L/s, periodic | - | **250** | - | 500 |

**Notes:** 1) All units g/m$^3$ unless otherwise stated.
2) Simulated monitoring point defined as the downstream toe of the dam.

The scenarios modelled are simplistic and are intended to be used to identify potentially viable options for mitigation water quality effects at the surface water bodies near the Macraes III project. For the purpose of this assessment, passive treatment of WRS seepage has not been included in any mitigation scenario.

Design of an updated water management plan for the site should involve further refinement of the concepts presented in this report. This process would include provision of more detailed design of collection points for TSF discharges, passive water treatment systems and management of drainage from WRS's. Additionally, bench scale studies of various mixtures of passive treatment media would yield more accurate information on removal efficiencies for sulphate, arsenic, iron and other contaminants.

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| | |
|---|---|
| Africa | + 27 11 254 4800 |
| Asia | + 852 2562 3658 |
| Australia & New Zealand | + 61 7 3721 5400 |
| Europe | + 44 356 21 42 30 20 |
| North America | + 1 800 275 3281 |
| South America | + 55 21 3095 9500 |

solutions@golder.com
www.golder.com

**TAKAPUNA**

Tel [64] (9) 486 8068
Fax [64] (9) 486 8072

Level 2
Takapuna Business Park
4 Fred Thomas Drive
Takapuna 0740
Auckland

(PO Box 33-849
Takapuna 0622)

**CHRISTCHURCH**

Tel [64] (3) 377 5696
Fax [64] (3) 377 9944

Level 4
115 Kilmore Street
Christchurch 8013

(PO Box 2281
Christchurch 8140)

**TAURANGA**

Tel [64] (7) 928 5335
Fax [64] (7) 928 5336

78 Maunganui Road
Tauranga 3116

(PO Box 13611
Tauranga Central
Tauranga 3141)

**DUNEDIN**

Tel [64] (3) 479 0390
Fax [64] (3) 474 9642

Level 9A
John Wickliffe House
265 Princes Street
Dunedin 9016

(PO Box 1087
Dunedin 9054)

**NELSON**

Tel [64] (3) 548 1707
Fax [64] (3) 548 1727

Level 3
295 Trafalgar Street
Nelson 7010

(PO Box 1724
Nelson 7040)


Golder Associates